Spring 5-15-2017

Examining the Lumbar Movement Pattern During Functional Activities in People With Low Back Pain

Andrej Vincent Marich

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Examining the Lumbar Movement Pattern During Functional Activities

in People With Low Back Pain

by

Andrej Vincent Marich

A dissertation presented to
The Graduate School
of Washington University in
partial fulfillment of the
requirements for the degree
of Doctor of Philosophy

May 2017
St. Louis, Missouri
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Acknowledgments

The phrase “it takes a village” is applicable to many things in life, including the completion of a Ph.D. The work presented in this dissertation would not be possible without the support and guidance of many talented and caring individuals.

First, I would like to acknowledge and thank my Ph.D. mentor, Dr. Linda Van Dillen. Linda has always provided levelheaded guidance throughout the many highs and lows during my time in the Movement Science Program. Through her guidance, I have become a confident and structured researcher, and I am well-positioned to continue to contribute to the advancement of science and the physical therapy profession. I would like to thank Dr. Catherine Lang for always challenging me to think outside the box and for asking the questions that challenge my understanding of a topic. I would also like to thank Dr. Shirley Sahrmann who was always willing to listen and provide thought-provoking suggestions to my research projects. There is no better advocate for the profession as Shirley. Thank you to Dr. Gretchen Salsich for always making time to discuss my research projects, and for always being an enthusiastic supporter of my ideas. To Dr. Michael Mueller, I thank you for always being supportive and helping me focus my research questions into viable projects.

Thank you to the members of the Musculoskeletal Analysis Laboratory, Kristen Roles, Jennifer Jarvis, Dr. Sara Francois, Dr. Christopher Sorensen, Sara Putnam, and CT Hwang for the many hours they spent listening to presentations and assisting with my research projects. I would also like to thank the Musculoskeletal Research Group who listened to my presentations and provided valuable insight to my dissertation project at numerous Wednesday meetings.
I would like to acknowledge Drs. Michael Mueller, Gammon Earhart, and Catherine Lang who were the directors of the Movement Science Program during my time as a doctoral student. The directors, and the Program in Physical Therapy created an environment that allowed me to learn and grow professionally.

I would like to thank my family and friends who have all supported me and helped in the completion of this dissertation project in one way or another. Finally, I would like to thank Cynthia Marich for her support, belief and encouragement, and most of all, patience.

This dissertation was partially funded by the National Institute of Health/National Institute of Child Health and Human Development/National Center for Medical Rehabilitation Research grant R01HD047709, the National Institute of Health Doctoral Training in Movement Science grant T32 HD007434-23, the Foundation for Physical Therapy; Promotion of Doctoral Studies Scholarship, and the Dr. Hans and Clara Davis Zimmerman Foundation. The content is solely the responsibility of the authors and does not necessarily represent the official views of the funding agencies.

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May 2017
This dissertation is dedicated to my wife Cynthia and our amazing family. Thank you for your unconditional love and support.
Low back pain (LBP) is a highly prevalent condition that is often characterized by persistent pain and limitations in the performance of daily functional activities. The repeated use of altered movement patterns during the performance of daily functional activities is proposed to contribute to the development and course of LBP. Specifically, in the case of LBP, the proposed alteration of movement is one in which the lumbar spine moves more readily than other joints that can contribute to the movement. This altered movement pattern is proposed to contribute to accumulation of localized tissue stress, micro- and macro-trauma of lumbar spine tissues and LBP symptoms. The purpose of this dissertation is to examine the lumbar movement pattern used during performance of functional activities in people with and people without LBP.
In Chapter 2 we compared the lumbar movement pattern used during a standardized clinical test to the lumbar movement pattern used during the performance of a functional activity test in both back-healthy people and people with LBP. We found that the lumbar movement pattern used during the clinical test was significantly associated with the lumbar movement pattern used during the functional activity test. We also found that people with LBP and high levels of functional limitation demonstrated an altered lumbar movement pattern of greater lumbar excursion in the early phase of the test movement compared to BH people and people with LBP and low levels of functional limitation. Finally, we found that the amount of early-phase lumbar excursion was significantly associated with a person’s functional limitation.

In Chapter 3 we examined the consistency of the lumbar movement pattern when aspects of the functional activity test were varied. We found that compared to back-healthy people and people with LBP and low levels of functional limitation, people with LBP and high levels of functional limitation consistently displayed an altered lumbar movement pattern of greater early-phase lumbar excursion across test conditions. In addition, we found that the amount of early-phase lumbar excursion was significantly associated with a person’s functional limitation.

In Chapter 4, we examined the ability of people with LBP to modify their preferred lumbar movement pattern during a functional activity test, within a single session of motor skills training (MST). We also examined the effect of modifying the lumbar movement pattern on a person’s LBP symptoms, and the characteristics of people with LBP that influenced their ability to modify the lumbar movement pattern. We found that prior to training people with LBP displayed an altered movement pattern of greater early-phase lumbar excursion compared to back-healthy people. Following MST, we found that people with LBP were able to reduce significantly the
amount of early-phase lumbar excursion during the performance of the functional activity. We also found that a significant number of participants with LBP reported decreased LBP symptoms during the functional activity following the MST. Additionally, we found that the amount of early-phase lumbar excursion in the preferred movement, and the duration of LBP were significant predictors of a person’s ability to modify the preferred lumbar movement pattern following MST.

The results of this dissertation provide initial evidence (1) supporting the proposal that people with LBP adopt altered lumbar movement patterns during performance of functional activities, (2) that a person’s lumbar movement pattern is associated with functional limitation, (3) that people with LBP can modify the altered lumbar movement pattern, and (4) that modifying the lumbar movement pattern has an immediate effect of reducing symptoms during performance of a functional activity. Additional research is needed to examine whether the modified lumbar movement pattern is (1) retained, (2) transferred to additional functional activities, and (3) has an effect on a person’s functional limitation.
Chapter 1: Introduction

1.1 Low Back Pain is a Significant Public Health Problem

Musculoskeletal pain conditions such as low back pain (LBP) are highly prevalent\(^1\) and represent a significant and growing public health problem.\(^2\) Worldwide, LBP is the leading cause of non-fatal disability,\(^3\) with direct healthcare costs exceeding $30 billion annually.\(^6\) It is estimated that up to 80\% of adults will experience a LBP episode at some point in their lifetime.\(^1,7\) Less than 25\% of people will report complete recovery of symptoms and functional limitation in the 12 months following the initial onset of LBP symptoms.\(^3\) For many people, LBP becomes a long-term chronic condition with recurrent or persistent symptoms and limitations in function.\(^3,8\) In fact, limitations in the performance of daily functional activities are the top reason people with LBP seek initial and repeat medical care for a LBP problem.\(^9,10\) Therefore, identifying the processes proposed to contribute to the development and course of LBP is a priority for effective and efficient management.

1.2 Proposed mechanism for the development of LBP

The Kinesiopathologic Model (KPM) is a conceptual model that provides a framework for the processes that may contribute to the development and course of musculoskeletal pain conditions, including LBP. A primary assumption of the KPM is that LBP develops as a result of the repeated use of altered patterns of movement and postures during the performance of daily functional activities.\(^11\) The proposed pattern is one in which the lumbar spine moves more readily than other joints that could contribute to the movement or posture e.g., hip or thoracic spine.\(^11\) Over time, the repetition of the same pattern across the performance of daily functional activities
is proposed to produce sub-failure magnitude loading, concentrated tissue stress, and ultimately LBP symptoms.\textsuperscript{12, 13} Finally, it is proposed that the LBP symptoms will recur or persist until the pattern is modified.\textsuperscript{14, 15}

1.3 Examining the lumbar movement pattern

Previous studies have focused on whether or not there are differences in the lumbar movement pattern used between people with LBP and back-healthy people during a clinical test such as forward bending (FWB). The primary variable examined to index the lumbar movement pattern has been maximal lumbar excursion attained during the performance of different clinical tests.\textsuperscript{16} Differences in maximal lumbar excursion between people with LBP and back-healthy people, however, have been found to be inconsistent. For example, while some studies have documented that people with LBP display decreased maximal lumbar excursion compared to back-healthy people during FWB,\textsuperscript{17, 18} other studies have documented no differences in maximal lumbar excursion between people with LBP and back-healthy people.\textsuperscript{19, 20} Because people with LBP are proposed to display a movement pattern in which the lumbar spine moves more readily into its’ available range than other joints, more recent studies have examined other aspects of the lumbar movement pattern during standardized clinical tests.\textsuperscript{21-24} For example, Scholtes et al. examined the timing of lumbar movement during the clinical test of hip lateral rotation. The Scholtes et al. study reported that people with LBP displayed a movement pattern of early lumbar motion, in which the lumbar spine moved more readily into its available range compared to back-healthy people.\textsuperscript{22} Another study indexed the lumbar movement pattern by examining the contribution of lumbar spine excursion to total trunk excursion at increments of the clinical test movement of trunk lateral bending, and reported differences between subgroups of people with LBP.\textsuperscript{23}
Because most functional activities are performed in the early- to mid-ranges of motion of the lumbar spine,\textsuperscript{25-27} examining whether people with LBP also display a pattern of early lumbar motion during a functional activity may provide important information regarding a potential movement-related mechanism that could contribute to the development and course of LBP. A pattern of early lumbar motion used repeatedly across the performance of functional activities potentially could contribute to an accumulation of tissue stress from repetitive loading of the lumbar spinal tissues, and therefore contribute to the development and course of LBP symptoms.

\section*{1.4 Lumbar movement pattern during a functional activity}

One key assumption made in the clinic is that how someone moves during clinical tests provides insight into how someone moves during functional activities across his day. Therefore, it would be important to examine the relationship between a person’s lumbar movement pattern during standardized clinical tests and functional activity tests. Some investigators have examined aspects of a person’s lumbar movement pattern during the performance of either clinical or functional activity tests. Work to date, however, has not examined how the movement pattern during a clinical test is associated with movement pattern during a functional activity test. Rather prior work has examined the pattern of lumbar movement at different speeds and positions during a functional activity test\textsuperscript{28, 29} or tested for differences in the lumbar movement pattern between people with LBP and back-healthy people,\textsuperscript{21} or subgroups of people with LBP.\textsuperscript{24, 30} One recent study reported that maximal lumbar excursion during the clinical test of FWB was moderately associated with maximal lumbar excursion during a pick up an object and a sit-to-stand functional activity test ($r$=0.52-0.83).\textsuperscript{31} The study, however, was limited because it examined only maximal lumbar excursion and tested only back-healthy males. Therefore, it is
unknown whether the lumbar movement pattern during a clinical test is associated with the lumbar movement pattern during a functional activity test in people with LBP and back-healthy people.

1.5 The lumbar movement pattern and functional limitation

While LBP symptoms are an important factor often assessed during performance of clinical tests during an examination, the primary reason people with LBP seek medical care is because of limitations in the performance of daily functional activities.\textsuperscript{9,10} Studies that have examined the relationship between a person’s lumbar movement pattern and functional limitations have focused on maximal lumbar excursion. These studies have reported associations ranging from $r=0.09$-0.73.\textsuperscript{32-34} Thus, maximal lumbar excursion is not a consistent predictor of a person’s functional limitations. It may be important, therefore, to examine the association between functional limitation and an aspect of a person’s lumbar movement pattern such as lumbar motion that occurs early in the test movement.

1.6 Consistency of the lumbar movement pattern during functional activities

An additional assumption of the KPM is that people with LBP adopt the same lumbar movement pattern across a range of functional activities.\textsuperscript{11} Although some studies have examined the lumbar movement pattern during a single functional activity test,\textsuperscript{35-37} very little has been reported on the consistency of the lumbar movement pattern used across multiple functional activity tests. Thomas et al. reported that BH people displayed a consistent ratio of spine and hip motion when the target locations of a reaching test were varied.\textsuperscript{29,38} Alqhtani et al. examined the association between maximal lumbar excursion during the FWB test and three functional activity tests in
back-healthy males.\textsuperscript{31} These investigators, however, examined only maximal lumbar excursion, and only reported on the association between the clinical test and each functional activity test. Therefore, it is unknown whether the lumbar movement pattern used during one functional activity is similar to the lumbar movement pattern used during another functional activity. An important first step to examine the consistency of the use of a lumbar movement pattern across activities would be to vary the demands of a single functional activity test and examine the consistency of the person’s lumbar movement pattern.

1.7 Modifying the lumbar movement pattern

Prior research has reported that people with LBP display a movement pattern of early lumbar motion during clinical tests, and the movement pattern is associated with the persons’ LBP symptoms.\textsuperscript{14, 15, 39, 40} Additionally, when the lumbar movement pattern is modified to reduce the amount of early lumbar motion during performance of the clinical test movement, a persons’ LBP symptoms improve.\textsuperscript{14, 15} Additional work has shown that with practice people with LBP can reduce the amount of early lumbar motion displayed during the clinical tests of hip lateral rotation and hip medial rotation.\textsuperscript{22, 41} Since the primary reason people with LBP seek medical care is because of limitations in the performance of daily functional activities it would be important to examine the ability of people with LBP to modify their lumbar movement pattern during a functional activity. Additionally, it would be important to examine the effect of modifying the lumbar movement pattern during a functional activity on a person’s LBP symptoms, and the characteristics of people with LBP that influence their ability to modify the lumbar movement pattern.
1.8 Primary purposes

There were 3 primary purposes of this project. The first was to compare the lumbar movement pattern used during a clinical test to the pattern used during a functional activity test, and evaluate the association between the lumbar movement pattern during the two tests and LBP-related functional limitation. The second purpose was to examine the consistency of the lumbar movement pattern used when aspects of a functional activity test were varied. The third purpose was to examine the (1) ability of a person with LBP to modify his preferred lumbar movement pattern during a functional activity within a single session of motor skills training, and (2) effect of the modification on LBP symptoms during performance of the activity. Additionally, we were interested in examining the characteristics of people with LBP that influence their ability to modify the lumbar movement pattern.

Specific Aim 1: Examine the lumbar movement pattern during a clinical test of forward bending (FWB) and a functional activity test of picking up an object (PUO) in people with LBP and back-healthy people, and examine the association between the lumbar movement pattern during each test and LBP-related functional limitation.

**Hypothesis 1a:** The lumbar movement pattern observed during a clinical test will be associated with the lumbar movement pattern observed during a functional activity test in both people with LBP and back-healthy people.

**Hypothesis 1b:** Compared to back-healthy people, people with LBP will demonstrate greater amounts of early phase lumbar excursion during both a clinical test and a functional activity test.
**Hypothesis 1c:** The amount of early phase lumbar excursion during each test will be associated with a person’s LBP-related functional limitation.

**Specific Aim 2:** Examine the effect on the lumbar movement pattern of varying the location of an object during performance of the functional activity test of picking up an object, in people with LBP and back-healthy people, and examine the association between the lumbar movement pattern during each test and LBP-related functional limitation.

**Hypothesis 2a:** Compared to back-healthy people, people with LBP will display greater amounts of early phase lumbar excursion during a functional activity test performed at various heights and distances.

**Hypothesis 2b:** The amount of early phase lumbar excursion during performance of the functional activity tests will be associated with a person’s LBP-related functional limitation.

**Specific Aim 3:** Examine the ability of people with LBP to modify their lumbar movement pattern during a functional activity test within a single session of motor skills training. Examine the effect of modifying the lumbar movement pattern on LBP symptoms, and examine the characteristics of people with LBP that influence the ability to modify their lumbar movement pattern.

**Hypothesis 3a:** People with LBP will demonstrate the ability to modify the lumbar movement pattern by reducing the amount of early phase lumbar excursion during a functional activity following a single session of motor skill training.
**Hypothesis 3b:** Modifying the lumbar movement pattern by reducing the amount of early phase lumbar excursion will result in an improvement in LBP symptoms during the performance of the functional activity test.

**Hypothesis 3c:** The ability to modify the lumbar movement pattern will be associated with demographic variables, hamstring extensibility, lumbar alignment, and LBP and movement-related characteristics.
1.9 Reference List


Chapter 2: Lumbar Movement Pattern During a Clinical Test and a Functional Activity Test in People With and People Without Low Back Pain

This chapter has been submitted for publication:
2.1 Abstract

**Background:** It is assumed that the lumbar movement pattern observed during a clinical test is representative of the lumbar movement pattern used during a functional activity. Very little is known about the how the lumbar movement pattern during a clinical test is associated with the lumbar movement pattern during a functional activity, and how the lumbar movement pattern is associated with functional limitation. The purpose of this study was to examine the lumbar movement pattern during a clinical test and a functional activity test in people with and people without low back pain (LBP), and the relationship of lumbar motion to LBP-related functional limitation.

**Methods:** Case-control study. 16 back-healthy adults and 32 people with chronic LBP. Participants performed a standardized clinical test and a functional activity test. Maximal lumbar excursion and lumbar excursion at 0-50% and 50-100% of movement time were examined.

**Results:** Significant associations were present between the two movement tests for both back-healthy people and people with LBP (r=0.47-0.73). People with LBP and high levels of functional limitation demonstrated greater lumbar motion in the 0-50% of movement time interval during the functional activity test ($\eta^2_{\text{partial}}=0.26$). In people with LBP the amount of lumbar motion in the 0-50% of movement time interval for both tests was significantly associated with functional limitation ($r=0.43-0.62$).

**Conclusion:** Lumbar movement patterns were similar between the two tests, and lumbar motion early in the movement of a functional test was related to functional limitation.
Key Words: Low back pain, movement pattern, functional activity
2.2 Introduction

Low back pain (LBP) is a highly prevalent musculoskeletal condition with a high rate of recurrence. For many people, LBP becomes a chronic condition characterized by fluctuating or persistent pain and limitations in performance of functional activities. The primary reasons people with chronic LBP seek repeat medical care include difficulty performing regular activities (98%) and an increase in pain (64%). Thus, for many people, LBP becomes a long-term, function-limiting condition. Identifying the processes proposed to contribute to the development and course of LBP is a priority for effective and efficient management.

One conceptual model that describes the processes that contribute to the development and course of LBP is the Kinesiopathologic Model. Based on the model, LBP results from the repeated use of stereotypic, direction-specific, lumbar movement patterns throughout the day. The typical pattern is characterized by the lumbar spine moving more readily in a specific direction(s) than other joints such as the thoracic spine or hip. The repeated use of the same patterns across activities is suggested to produce sub-failure magnitude loading, tissue stress, and LBP symptoms. Finally, it is proposed that until a person’s stereotypic pattern is modified, the LBP will recur or persist.

Typically, the person’s lumbar movement pattern is identified during standardized clinical examination tests. During a clinical test, the person performs a movement or assumes a position while a judgment is made about how readily the lumbar spine moves. Differences in lumbar movement patterns identified during clinical tests have been reported between people with LBP and back-healthy (BH) people, as well as between subgroups of people with LBP.
One key clinical assumption is that findings from clinical tests are relevant to the patient’s presentation. In particular, the lumbar movement patterns during clinical tests are considered to provide insight into how someone moves during functional activities across his day. To our knowledge this assumption has not been examined systematically in people with LBP and BH people.

A second key assumption is that the lumbar movement patterns used during clinical tests and functional activities are associated with LBP-related limitations in function. When the association between total lumbar excursion and functional limitation has been examined, the findings are mixed.\textsuperscript{14, 21, 27} Since most functional activities are performed in the early to mid-ranges of lumbar motion,\textsuperscript{3, 4, 23} we reasoned that it would be logical to examine the association between functional limitations and lumbar excursion in the early part of the movement, particularly during a functional activity test. To our knowledge, such associations have not been examined.

The purpose of this study was to examine (1) the lumbar movement pattern used during a clinical test and a functional activity test, in people with LBP and BH people, (2) differences in lumbar excursion during a clinical test and a functional activity test between BH people and people with LBP with low and high levels of functional limitation, and (3) the association between lumbar excursion and functional limitation in people with LBP. It was hypothesized that (1) the lumbar movement pattern would be related between the two tests in both BH people and people with LBP, (2) compared to BH people, people with LBP and high levels of functional limitation would demonstrate a greater amount of lumbar excursion early in the movement during the two tests, and (3) a person’s functional limitations would be associated with lumbar excursion during
both tests, particularly lumbar excursion displayed in the early part of the movement during both tests.

2.3 Materials and Methods

2.3.1 Participants

Thirty-two people with LBP and 16 BH people were recruited from the St. Louis, MO region. Inclusion criteria for all participants included aged 18 to 60 and body mass index (BMI) ≤ 30 kg/cm². Participants with LBP were included if they reported a history of LBP for ≥ 12 months and LBP symptoms present greater than ½ the days of the year. A history of LBP was defined as LBP that resulted in (1) 3 or more consecutive days of missed work or school, or altered daily activities, or (2) seeking some type of LBP-related health intervention. Participants with LBP were excluded if they reported (1) pain, numbness, or tingling below the knee, (2) previous lumbar surgery or trauma, (3) a specific spinal diagnosis (i.e. spinal stenosis), (4) were in an acute flare-up, (5) current pregnancy, (6) systemic infection or inflammatory conditions, or (7) LBP-related worker’s compensation or litigation. BH participants were excluded if they reported a history of LBP as defined. Because we were interested in how functional limitation was related to movement, participants with LBP with a modified Oswestry Low Back Disability Questionnaire (mODI) score < 20% were classified as LBP-Low, and participants with a mODI score ≥ 20% were classified as LBP-High. All participants provided informed consent approved by the Human Research Protection Office of Washington University in St Louis School of Medicine prior to participating in the study.

2.3.2 Clinical Measures

Prior to laboratory testing, participants completed self-report measures that included (1) a
demographic and LBP-history form, (2) a numeric pain rating scale (NRS),\textsuperscript{7,10} (3) the mODI, (4) the Fear-Avoidance Beliefs Questionnaire (FABQ),\textsuperscript{35} and (5) the Short-Form 36 Health Survey.\textsuperscript{37}

2.3.3 Laboratory Measures

Participants performed the clinical test of Forward Bend (FWB) and functional activity test of Pick Up an Object (PUO) presented in random order. For both tests, the participant was told to stand in a comfortable position with feet pelvis-width apart. For the FWB test, the participant bent forward as far as possible at a self-selected speed keeping the knees straight, and then returned to the starting position. For the PUO test, a small lightweight plastic container was placed at a height equal to the apex of the fibular head, and a distance equal to 50\% of the trunk length as measured from the 7\textsuperscript{th} cervical (C7) to the 1\textsuperscript{st} sacral (S1) vertebrae. The participant was instructed to pick up the container using both hands and return to the starting position. In order to simulate the functional activity under typical conditions, no other instructions were provided to the participant. If a participant self-selected a squatting strategy to perform the activity, after completion of the initial 3 trials he performed an additional 3 trials in which he was instructed to perform the activity without squatting. No additional instructions were provided about lower extremity movements. The non-squatting trials were used in the analyses reported. Kinematic data were collected using an 8-camera, 3-dimensional motion capture system (Vicon Motion Systems, LTD, Denver, CO) with a sampling rate of 120Hz. Retroreflective markers were placed on predetermined landmarks of the trunk, pelvis, and lower extremities (Table 2.1).
Table 2.1. Locations of retroreflective markers.

<table>
<thead>
<tr>
<th>Marker</th>
<th>Location Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acromion†</td>
<td>Center of acromion</td>
</tr>
<tr>
<td>Manubrium</td>
<td>Superior aspect of manubrium</td>
</tr>
<tr>
<td>C7‡</td>
<td>Spinous process 7th cervical vertebrae</td>
</tr>
<tr>
<td>T3</td>
<td>4 cm lateral to the spine: 1/4 distance C7 to T12</td>
</tr>
<tr>
<td>T6‡</td>
<td>1/2 distance from C7 to T12</td>
</tr>
<tr>
<td>T10</td>
<td>4 cm lateral to the spine: 2/3 distance T6 to T12</td>
</tr>
<tr>
<td>Lateral T12</td>
<td>Lateral midline of body, directly lateral to T12</td>
</tr>
<tr>
<td>T12‡/L1*</td>
<td>Spinous process 12th thoracic or 1st lumbar vertebrae</td>
</tr>
<tr>
<td>L2</td>
<td>4 cm lateral to the spinous process of the 2nd lumbar vertebrae</td>
</tr>
<tr>
<td>L3‡</td>
<td>Spinous process 3rd lumbar vertebrae</td>
</tr>
<tr>
<td>L4</td>
<td>4 cm lateral to the spinous process of the 4th lumbar vertebrae</td>
</tr>
<tr>
<td>L5/S1*</td>
<td>Spinous process 5th lumbar vertebrae or ½ distance from L5 to S2</td>
</tr>
<tr>
<td>Iliac Crest†</td>
<td>Most superior aspect of iliac crest</td>
</tr>
<tr>
<td>PSIS†</td>
<td>Most superior aspect of posterior superior iliac spine</td>
</tr>
<tr>
<td>Sacrum</td>
<td>Distal aspect of sacrum</td>
</tr>
<tr>
<td>ASIS†</td>
<td>Most prominent aspect of anterior superior iliac spine</td>
</tr>
<tr>
<td>Greater Trochanter†</td>
<td>Most superior aspect of greater trochanter</td>
</tr>
<tr>
<td>Thigh†</td>
<td>4-marker plate lateral distal aspect of thigh</td>
</tr>
<tr>
<td>Shank†</td>
<td>4-marker plate lateral distal aspect of shank</td>
</tr>
<tr>
<td>Knee†</td>
<td>Lateral and medial aspect of knee joint line</td>
</tr>
<tr>
<td>Ankle†</td>
<td>Prominent bony aspect of the lateral and medial malleoli</td>
</tr>
</tbody>
</table>

* A marker was placed at either location depending on the marker set used
† Marker location included markers placed on bilateral landmarks
‡ Marker location included markers placed on the spinous process as well as at 4cm lateral to the spinous process
2.3.4 Sub-study of Laboratory Measures

A separate sub-study was conducted to test for differences in lumbar excursion with two different retroreflective marker sets during the FWB and PUO tests. This sub-study was conducted because 16/32 (50%) of the participants with LBP were obtained from a second ongoing study that used a different marker set. The marker set used in the second study differed from the marker set in Table 2.1 with regard to two marker locations. Specifically, in the second study markers were placed superficial to the spinous process of the 12th thoracic (T12) instead of the 1st lumbar (L1) vertebrae, and the first sacral (S1) instead of the 5th lumbar (L5) vertebrae. In the sub-study, a separate sample of 12 participants (BH: n=6; LBP: n=6) performed the FWB and PUO tests wearing all markers from both marker sets simultaneously. Paired samples t-tests were conducted to test for differences in the variables of interest calculated using each of the two marker sets.

2.3.5 Data Processing

A vector from the C7 marker to the T12 or L1 marker defined the thoracic segment. The lumbar segment was defined by a vector from the T12 or L1 marker to the L5 or S1 marker. The pelvis segment was defined by markers at the distal aspect of the sacrum, the anterior superior iliac spines, posterior superior iliac spines, and iliac crests. The thigh segment was defined by a vector from markers on the knee joint line and greater trochanter.

Kinematic data were processed in Visual 3D software (C-Motion, Inc., Germantown, MD) and custom programs written in MATLAB software (MathWorks Inc., Natick, MA). A 4th-order, dual-pass Butterworth filter with a cut-off frequency of 3 Hz was applied to marker position data. Angular displacement of the thoracic, lumbar, pelvis, and knee segments in the sagittal plane...
were calculated across time. Thoracic excursion was calculated as the angular displacement of the thoracic segment relative to the lumbar segment. Lumbar excursion was calculated as the angular displacement of the lumbar segment relative to the pelvis segment. Pelvis excursion was calculated as the angular displacement of the pelvis segment relative to the thigh segment. Starts and stops of motion were determined, and movement time (MT) was calculated. The start of motion was defined as a 1° change in sagittal excursion of the trunk from the initial standing position. The trunk was defined as the combined thoracic, lumbar, and pelvis segments from the initial standing position. The stop of motion was defined as the point equal to 98% of the maximal forward trunk excursion.

Thoracic, lumbar, pelvis and knee kinematics were examined from the start to the stop of forward trunk motion. Maximal excursion as well as excursion from 0-50% and 50-100% of MT was calculated for the each segment. To examine consistency of the kinematic measures, intraclass correlation coefficients (ICC) and standard error of the measure were calculated using the 16 BH participants from this study. ICC’s for FWB for the variables of lumbar excursion, and lumbar excursion from 0-50% and 50-100% of MT were determined to be acceptable (ICC\(_{[3,1]}=0.83\text{-}0.95\)) with calculated standard errors of the measure from 1.40°-1.60°. For maximal lumbar excursion, and lumbar excursion from 0-50% and 50-100% of MT for the PUO test, ICC’s were determined to be acceptable (ICC\(_{[3,1]}=0.88\text{-}0.91\)), with calculated standard errors of the measure from 0.95°-1.52°.

2.3.6 Data Analysis

The sample size was determined based on a desired power of 80%, with \(p<.05\), and an effect size (Pearson correlation) of .45; an effect size we considered to be a reasonable size correlation.
between two variables for the relationship to be important. Statistical analyses were performed with SPSS version 23.0 (IBM® SPSS® Statistics Inc., Chicago, IL). Descriptive statistics were analyzed using a chi-square, one-way analysis of variance (ANOVA), or independent samples t-test. Correlation coefficients were calculated to index the relationship between lumbar excursion during the FWB and PUO tests for maximal lumbar excursion and lumbar excursion at 50% increments of MT. One-way ANOVA tests were conducted to test for differences among the groups for the FWB and PUO test at each segment for (1) maximal excursion, and (2) excursion at 50% increments of MT. A Fisher’s least significant difference (LSD) post-hoc test was performed for significant ANOVA test results, and effect sizes ($\eta^2_{\text{partial}}$) were calculated. Correlation coefficients were calculated to examine the relationship between mODI and maximal lumbar excursion, and lumbar excursion at 50% increments of MT. All statistical analyses were two-tailed tests with a significance level of $p \leq .05$.

2.4 Results

2.4.1 Participant Characteristics

There were no differences in gender distribution, age, height, weight, or BMI among the 3 groups. There were no differences in current, average, or worst pain intensity between the LBP groups ($Ps > .05$). As expected, the mODI score was significantly greater in the LBP-High group compared to the LBP-Low group ($P < .01$). The LBP-High group had significantly greater FABQ scores for both the physical activity and work subscales ($Ps < .05$). For FWB, the BH participants had significantly shorter movement time compared to both LBP groups ($P < .01$; Table 2.2).
Table 2.2. Descriptive statistics for participant characteristics for the back-healthy (BH), low back pain and Modified Oswestry Low Back Disability Questionnaire (mODI) scores < 20% (LBP-Low), and the low back pain and mODI scores ≥ 20% (LBP-High) groups.*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>BH  (n = 16)</th>
<th>LBP-Low (n = 13)</th>
<th>LBP-High (n = 19)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female, n (%)</td>
<td>9 (56)</td>
<td>5 (32)</td>
<td>10 (53)</td>
<td>.61</td>
</tr>
<tr>
<td>Age, y</td>
<td>32.1 (9.4)</td>
<td>35.1 (12.3)</td>
<td>33.0 (8.6)</td>
<td>.71</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.72 (0.12)</td>
<td>1.76 (0.10)</td>
<td>1.72 (0.99)</td>
<td>.44</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>71.8 (11.1)</td>
<td>71.3 (12.2)</td>
<td>76.3 (13.6)</td>
<td>.44</td>
</tr>
<tr>
<td>mODI†</td>
<td>7.2 (5.9)</td>
<td>26.8 (6.4)</td>
<td>&lt;.01</td>
<td></td>
</tr>
<tr>
<td>Low back pain duration, y</td>
<td>4.8 (5.6)</td>
<td>9.5 (7.2)</td>
<td>.06</td>
<td></td>
</tr>
<tr>
<td>Pain intensity†</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td>3.5 (2.0)</td>
<td>3.5 (2.1)</td>
<td>.98</td>
<td></td>
</tr>
<tr>
<td>Worst (prior 7 days)</td>
<td>6.4 (2.7)</td>
<td>6.2 (2.0)</td>
<td>.78</td>
<td></td>
</tr>
<tr>
<td>Average (prior 7 days)</td>
<td>3.6 (1.7)</td>
<td>4.3 (1.9)</td>
<td>.32</td>
<td></td>
</tr>
<tr>
<td>FABQ-physical activity subscale‡</td>
<td>10.0 (4.7)</td>
<td>14.2 (6.3)</td>
<td>.05</td>
<td></td>
</tr>
<tr>
<td>FABQ-work subscale§</td>
<td>4.8 (6.9)</td>
<td>11.5 (8.8)</td>
<td>.03</td>
<td></td>
</tr>
<tr>
<td>Movement time, sec</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forward Bend test</td>
<td>1.9 (0.5)</td>
<td>2.6 (1.2)</td>
<td>2.9 (0.9)</td>
<td>&lt;.01‡</td>
</tr>
<tr>
<td>Pick Up an Object test</td>
<td>1.2 (0.2)</td>
<td>1.5 (0.3)</td>
<td>1.4 (0.3)</td>
<td>.06</td>
</tr>
</tbody>
</table>

Bold font indicates significance at $P \leq .05$

* Values expressed are means (SD) unless otherwise indicated.

† Modified Oswestry Low Back Disability Questionnaire. Scores range from 0 to 100%

‡ Scores range from 0 ("no pain") to 10 ("worst pain imaginable")

§ Fear avoidance behavior questionnaire, scores range from 0 to 24

‖ Fear avoidance behavior questionnaire, scores range from 0 to 42

# Indicates significant difference between the BH group and both LBP groups
2.4.2 Relationship Between Movement Tests

Maximal lumbar excursion was significantly associated between the FWB and PUO tests for the BH \((r = 0.89, p < .01)\) and LBP participants \((r = 0.71, p < .01)\). Lumbar excursion from 0-50\% of MT was significantly associated between the two tests for the BH \((r = 0.73, p < .01)\) and LBP participants \((r = 0.73, p < .01; \text{Figure 2.1})\). Lumbar excursion from 50-100\% of MT also was significantly associated between the two tests for the BH \((r = 0.63, p = .01)\) and LBP participants \((r = 0.45, p = .01)\).
Figure 2.1. Scatterplots of lumbar excursion from 0-50% of movement time (MT) for the Forward Bending test (FWB) and the Pick Up an Object test (PUO) for the (a) back-healthy participants ($r = 0.73$, $r^2 = 0.53$) and (b) participants with low back pain ($r = 0.73$, $r^2 = 0.53$). Correlations are significant ($p \leq .05$).
2.4.3 Kinematics

Marker set comparisons. (Table 2.3) There were no differences between the two marker sets for maximal excursion or excursion from 0-50% or 50-100% of MT for the thoracic, lumbar, or pelvis segments ($p > .05$) for the FWB test of the PUO test.

Forward Bend test. (Table 2.4) There were no differences among the 3 groups in lumbar, or pelvis segments for maximal excursion, or excursion at 50% increments of MT ($p > .05$).

Pick Up an Object test. (Table 2.4) There were no differences among the 3 groups in the pelvis segment for maximal excursion ($p > .05$), or excursion at 50% increments of MT ($p > .05$). Compared to the other 2 groups, however, the LBP-High group had more maximal lumbar excursion ($p = .01$), and more lumbar excursion from 0-50% of MT ($p < .01$). Because the FABQ-PA and FABQ-W subscale scores were different between the LBP groups, separate ANOVA tests were conducted examining lumbar excursion from 0-50% of MT for the PUO test, with each FABQ subscale score as a covariate. Compared to the other 2 groups, the LBP-High group had significantly more lumbar excursion from 0-50% of MT when including FABQ-PA subscale scores as a covariate ($F=7.38$, $p = .01$), and FABQ-W subscale scores as a covariate ($F = 8.79$, $p < .01$).
Table 2.3. Means in degrees, standard deviations and associated $p$ values for the sub-study examining the two kinematic marker sets for maximal lumbar and pelvis segment excursion as well as lumbar excursion from 0-50\% and 50-100\% of movement time (MT) during the Forward Bending test and the Pick Up an Object test for the back-healthy (BH) participants and participants with low back pain (LBP).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>BH (n=6)</th>
<th>LBP (n=6)</th>
<th>$p$-value</th>
<th>BH (n=6)</th>
<th>LBP (n=6)</th>
<th>$p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Marker</td>
<td>Marker</td>
<td></td>
<td>Marker</td>
<td>Marker</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Set 1*</td>
<td>Set 2\†</td>
<td></td>
<td>Set 1*</td>
<td>Set 2\†</td>
<td></td>
</tr>
<tr>
<td><strong>Forward Bending test</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lumbar excursion Maximal</td>
<td>33.4 (7.7)</td>
<td>33.5 (6.1)</td>
<td>.98</td>
<td>31.9 (5.7)</td>
<td>32.4 (5.5)</td>
<td>.85</td>
</tr>
<tr>
<td>0-50% of MT</td>
<td>18.7 (6.3)</td>
<td>19.1 (6.3)</td>
<td>.91</td>
<td>17.8 (3.4)</td>
<td>18.3 (3.6)</td>
<td>.65</td>
</tr>
<tr>
<td>50-100% of MT</td>
<td>14.6 (3.0)</td>
<td>14.4 (1.6)</td>
<td>.93</td>
<td>14.1 (2.5)</td>
<td>14.2 (2.5)</td>
<td>.91</td>
</tr>
<tr>
<td>Pelvis excursion Maximal</td>
<td>73.6 (11.3)</td>
<td>73.6 (11.3)</td>
<td>.99</td>
<td>75.5 (15.8)</td>
<td>75.4 (15.9)</td>
<td>.99</td>
</tr>
<tr>
<td><strong>Pick Up an Object test</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lumbar excursion Maximal</td>
<td>20.5 (5.4)</td>
<td>21.3 (4.4)</td>
<td>.79</td>
<td>19.2 (6.6)</td>
<td>19.4 (6.9)</td>
<td>.96</td>
</tr>
<tr>
<td>0-50% of MT</td>
<td>10.8 (3.1)</td>
<td>11.1 (2.5)</td>
<td>.83</td>
<td>8.7 (3.9)</td>
<td>9.0 (4.3)</td>
<td>.90</td>
</tr>
<tr>
<td>50-100% of MT</td>
<td>9.7 (2.6)</td>
<td>10.1 (2.1)</td>
<td>.76</td>
<td>10.6 (3.6)</td>
<td>10.4 (5.1)</td>
<td>.92</td>
</tr>
<tr>
<td>Pelvis excursion Maximal</td>
<td>39.2 (7.2)</td>
<td>39.2 (7.2)</td>
<td>.99</td>
<td>47.5 (13.0)</td>
<td>47.8 (13.2)</td>
<td>.97</td>
</tr>
</tbody>
</table>

* Marker set 1 consisted of a lumbar segment from L1-L5.
† Marker set 2 consisted of a lumbar segment from T12-S1.
Table 2.4. Means (in degrees), standard deviations, and statistical values for segment excursions for maximal excursion as well as excursion at 50% increments of movement time (MT) during the Forward Bend test and for the Pick Up an Object test for back-healthy (BH) people and people with low back pain (LBP).

<table>
<thead>
<tr>
<th></th>
<th>BH (n=16)</th>
<th>LBP-Low (n=13)</th>
<th>LBP-High (n=19)</th>
<th>P-value</th>
<th>Effect size $^\dagger$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forward Bending test</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lumbar excursion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximal</td>
<td>33.8 (7.1)</td>
<td>32.7 (10.9)</td>
<td>36.8 (7.9)</td>
<td>.36</td>
<td>0.04</td>
</tr>
<tr>
<td>0-50% of MT</td>
<td>19.7 (4.7)</td>
<td>18.9 (6.6)</td>
<td>22.0 (4.8)</td>
<td>.23</td>
<td>0.06</td>
</tr>
<tr>
<td>50-100% of MT</td>
<td>13.9 (3.8)</td>
<td>13.8 (6.8)</td>
<td>14.8 (7.9)</td>
<td>.88</td>
<td>0.01</td>
</tr>
<tr>
<td>Pelvis excursion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximal</td>
<td>59.1 (15.3)</td>
<td>65.3 (12.9)</td>
<td>55.2 (16.0)</td>
<td>.19</td>
<td>0.07</td>
</tr>
<tr>
<td>0-50% of MT</td>
<td>30.6 (8.1)</td>
<td>34.8 (8.9)</td>
<td>29.9 (11.4)</td>
<td>.35</td>
<td>0.05</td>
</tr>
<tr>
<td>50-100% of MT</td>
<td>38.4 (8.4)</td>
<td>35.8 (10.2)</td>
<td>30.3 (15.7)</td>
<td>.14</td>
<td>0.08</td>
</tr>
<tr>
<td><strong>Pick Up an Object test</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lumbar excursion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximal</td>
<td>21.3 (4.7)</td>
<td>21.6 (9.1)</td>
<td>27.2 (4.4)</td>
<td>.01*</td>
<td>0.19</td>
</tr>
<tr>
<td>0-50% of MT</td>
<td>9.7 (3.1)</td>
<td>9.3 (4.4)</td>
<td>13.5 (2.8)</td>
<td>&lt;.01*</td>
<td>0.26</td>
</tr>
<tr>
<td>50-100% of MT</td>
<td>11.7 (3.4)</td>
<td>12.2 (5.2)</td>
<td>13.9 (3.8)</td>
<td>.26</td>
<td>0.06</td>
</tr>
<tr>
<td>Pelvis excursion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximal</td>
<td>34.2 (12.0)</td>
<td>41.4 (9.2)</td>
<td>35.6 (7.6)</td>
<td>.13</td>
<td>0.09</td>
</tr>
<tr>
<td>0-50% of MT</td>
<td>13.7 (6.0)</td>
<td>15.6 (5.1)</td>
<td>13.8 (4.7)</td>
<td>.56</td>
<td>0.03</td>
</tr>
<tr>
<td>50-100% of MT</td>
<td>22.7 (6.9)</td>
<td>28.9 (7.8)</td>
<td>24.8 (6.3)</td>
<td>.06</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Bold font indicates significance at $P \leq .05$

* Indicates significant difference between the LBP-High group and both the BH and LBP-Low groups

$^\dagger$ Effect size is expressed as $\eta^2_{\text{partial}}$; (small = 0.01, medium = 0.06, large = 0.14)
2.4.4 Relationship to Functional Limitation

There were significant associations between maximal lumbar excursion and mODI for the FWB ($r = 0.38$, $p = .03$) and PUO tests ($r = 0.56$, $p < .01$). There were significant associations between lumbar excursion from 0-50\% of MT and mODI for the FWB ($r = 0.43$, $p = .02$) and PUO tests ($r = 0.62$, $p < .01$; Figure 2.2). There was not a significant association between lumbar excursion from 50-100\% of MT and mODI for the FWB test ($r = 0.15$, $p = .42$). The association between lumbar excursion from 50-100\% of MT and mODI, however, was significant for the PUO test ($r = 0.35$, $p = .05$).
Figure 2.2. Scatterplots of modified Oswestry Low Back Disability Questionnaire (mODI) score and lumbar excursion from 0-50% of movement time (MT) during the (a) Forward Bending (FWB) test \( (r = 0.43, p = .02) \) and (b) Pick Up an Object (PUO) test \( (r = 0.62, p < .01) \) for all people with low back pain (LBP).
2.5 Discussion

Our purpose was to examine the association between the lumbar movement pattern during a clinical test and a functional activity test and to test for differences in lumbar excursion during the two tests in BH people and people with LBP. Additionally we were interested in the relationship between lumbar excursion during the two tests and functional limitations. As hypothesized, the lumbar movement pattern between FWB and PUO was significantly associated in both BH people and people with LBP, indicating a similar lumbar movement pattern is used during the two tests. There were no differences among the groups in lumbar excursion during the FWB test, however, in the early part of the PUO test, the LBP-High group displayed more lumbar excursion compared to the other groups. Thus the LBP-High group was moving the lumbar spine more readily during the functional activity test compared to the other two groups. We also found that lumbar excursion, particularly early in the test movement, was associated with the person’s functional limitations. These findings suggest that the lumbar movement pattern during a clinical test reflects how a person moves the lumbar spine during a functional activity and people with high levels of functional limitation use a greater amount of lumbar excursion during the early part of a functional activity test. In addition, the lumbar movement pattern, particularly early in the range of a test movement, appears to be important to a person’s functional limitations.

Studies where participants performed 2 or more movement tests have primarily focused on differences between (1) BH people and people with LBP,25 (2) LBP subgroups,13,15 or (3) patterns of movement at different movement speeds and object locations rather than the relationship between the movements.28,29 A recent study by Alqhtani et al. reported maximal
lumbar excursion during FWB was associated with maximal lumbar excursion during a functional activity test for the upper lumbar ($r = 0.57$), and lower lumbar ($r = 0.83$) segments. Different from the current study, however, the sample in the Alqhtani study included only BH males, there was no examination of lumbar excursion at increments of movement time, and the functional activity test involved picking up an object from the floor. Thus, it is unknown whether, in people with LBP, the lumbar movement pattern during a clinical test is associated with the lumbar movement pattern during a functional activity test. It also is unknown whether there are differences in the lumbar movement pattern in the early or late parts of movement. We examined lumbar excursion early in the test movement because most functional activities require between 3%-60% of lumbar motion. To our knowledge, the current study is the first to examine the relationship between the movement pattern during both a clinical test and a functional activity test in both BH and people with LBP.

A number of studies have examined movement characteristics during FWB, comparing BH people and people with LBP. While the general findings suggest that people with LBP display less maximal lumbar excursion compared to BH people, the subset of studies of FWB examining only people with non-specific LBP report no differences in maximal lumbar excursion compared to BH people. Similar to previous studies of people with non-specific LBP, we found no differences among the groups in maximal lumbar excursion during FWB. Esola et al. re reported that people with LBP displayed a greater lumbar-to-hip ratio from 30°-60° of FWB compared to BH people despite no differences in maximal lumbar excursion. The authors suggested that people with LBP use more of their available lumbar motion early in the movement compared to BH people. We investigated lumbar excursion at increments of...
movement time during the two movement tests because of prior work documenting differences in the lumbar movement pattern during other clinical tests (e.g., forward bend) between BH people and people with LBP, and subgroups of people with LBP. In the current study there were no differences in lumbar excursion at any increment of movement time during FWB among the groups. The differences in findings for the FWB test in our study compared to the Esola et al. study may be because we examined lumbar excursion rather than a ratio of lumbar to hip excursion.

Prior studies examining the association between functional limitations and maximal lumbar excursion during a FWB test have documented correlations ranging from 0.09-0.73. We obtained a moderate association ($r=0.38$, $r^2=0.14$, $p=0.04$) between a person’s functional limitations and maximal lumbar excursion during the FWB test. When lumbar excursion was examined in MT increments, the association to functional limitations was greater in the early ($r=0.43$, $r^2=0.18$, $p=0.02$) compared to the late part of the movement ($r=0.15$, $r^2=0.02$, $p=0.42$). Thus, a person’s functional limitations appear to be more related to how the person moves in the early, rather than the late part of a clinical test.

A unique aspect of the current study is that we also examined the association between functional limitations and the lumbar movement pattern during a functional activity test. Our interest was based on the fact that (1) limitations in performance of functional activities is a key reason people with chronic LBP seek repeat treatment, and (2) functional activities typically are performed in the early to mid-ranges of lumbar motion. We found a large association between maximal lumbar excursion during the PUO test and a person’s functional limitations ($r = 0.56$, $r^2 = 0.31$, $p < .01$). When examined in MT increments, the association between
functional limitations and lumbar excursion was larger in the early part \( (r = 0.62, r^2 = 0.38, p < .01) \) than the late part of movement \( (r = 0.35, r^2 = 0.12, p = .05) \). To our knowledge, no studies have examined the association between functional limitations and lumbar excursion during phases of a functional activity test.

Overall, we found that the relationship between maximal lumbar excursion and functional limitations was larger and explained more about a person’s limitations with the functional activity test than the clinical test. Additionally, the association between the early phase of movement and functional limitations was larger for the PUO test than for the FWB test. These findings suggest that treatments directed at changing the way a person moves in the early part of a functional activity may have a larger and more direct impact on function than other types of treatment.

One potential limitation of the study is that the sample included people from a separate study that used a different set of retroreflective markers. To examine the potential contribution of the different marker sets to the differences in lumbar excursion we identified, we conducted a separate sub-study. When people wearing both marker sets performed each of the tests (FWB and PUO) there were no differences in the values of the excursion variables of interest in this study. A second limitation of this study is that the object in the functional activity test was placed in a position that was scaled to the individual. Additionally, the participants were provided standardized instructions to pick up the object with both hands and not move their feet. It is unknown whether these standardizations represent the participant’s typical performance of a functional activity.
2.6 Conclusions

The lumbar movement pattern was similar between a clinical test and a functional activity test, for both BH people and people with LBP. There were no differences among the groups in lumbar excursion early in the movement during the clinical test of forward bending. People with LBP and high levels of functional limitation, however, displayed more lumbar excursion in the early phase of movement during a functional activity test compared to people with low levels of functional limitation and BH people. The amount of lumbar excursion early in the movement for both the clinical and functional activity test was related to a person’s functional limitation. Future work should examine whether people with LBP and high levels of functional limitation continue to display greater lumbar excursion in the early phase of movement when aspects of the functional activity are varied.
2.7 Reference List


13. Gombatto SP, Collins DR, Engsberg JR, Sahrmann SA, Van Dillen LR. Patterns of lumbar region movement during trunk lateral bending in two different subgroups of


[38]


[39]
Chapter 3: Consistency of a Lumbar Movement Pattern Across Functional Activities in People With Low Back Pain

This chapter has been accepted for publication:
Marich AV, Hwang CT, Salsich GB, Lang CE, Van Dillen, LR. Consistency of a lumbar movement pattern across functional activities in people with low back pain. *Clinical Biomechanics*; Accepted March 6, 2017.
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3.1 Abstract

**Background:** Limitation in function is a primary reason people with low back pain (LBP) seek medical treatment. Specific lumbar movement patterns, repeated throughout the day, have been proposed to contribute to the development and course of LBP. Varying the demands of a functional activity test may provide some insight into whether people display consistent lumbar movement patterns during functional activities. Our purpose was to examine the consistency of the lumbar movement pattern during variations of a functional activity test in people with LBP and back-healthy (BH) people.

**Methods:** 16 BH adults and 32 people with LBP participated. LBP participants were classified based on the level of self-reported functional limitations. Participants performed 5 different conditions of a functional activity test. Lumbar excursion in the first 50% (early phase) of movement was examined. The association between functional limitations and early phase lumbar excursion for each test condition was examined.

**Findings:** People with LBP and high levels of functional limitation demonstrated a consistent pattern of greater early phase lumbar excursion across test conditions ($p<.05$). For each test condition, the amount of early phase lumbar excursion was associated with functional limitation ($r=0.28-0.62$).

**Interpretation:** Our research provides preliminary evidence that people with LBP adopt consistent movement patterns during the performance of functional activities. Our findings indicate that the lumbar spine consistently moves more readily into its available range in people...
with LBP and high levels of functional limitation. How the lumbar spine moves during a functional activity may contribute to functional limitations.

**Key words:** Low back pain; movement; functional activity; functional limitation
3.2 Introduction

Low back pain (LBP) is a highly prevalent musculoskeletal pain condition that affects up to 80% of the population at some point in their lifetime.\(^1\) Limitation in the performance of daily activities is a primary reason people seek initial\(^2\) and repeat medical care for LBP.\(^3\) Since the performance of daily functional activities is such an important component of why people with LBP seek care, it seems imperative to examine how people with LBP perform their functional activities. Examination of the lumbar movement pattern during functional activities may provide insight into processes that may be contributing to the development and course of the LBP condition.

The Kinesiopathological (KP) model is a conceptual model that provides a framework for understanding how movements and postures used during functional activities may contribute to the development and course of musculoskeletal pain conditions.\(^4\) An assumption of the model is that musculoskeletal pain conditions develop as a result of the use of direction-specific patterns of movements and postures repeated throughout the day. In the case of LBP, it is proposed that people adopt a movement pattern during performance of functional activities in which the lumbar spine moves more readily into its available range than other joints that can contribute to the desired movement.\(^4-8\) Over time, the repetition of the same lumbar movement pattern across a range of everyday activities can lead to an accumulation of stress in the lumbar tissues, LBP symptoms, and eventually micro- and macro- level tissue injury.\(^9,10\)

In prior research, aspects of the lumbar movement pattern have been indexed using several different variables, including the onset and timing of movement of the lumbar spine relative to other joints,\(^6-8\) and the amount of lumbar excursion in a specific movement direction\(^6,7,11,12\) during standardized clinical tests such as forward bending in standing.\(^13,14\) Differences have
been reported between subgroups of people with LBP\textsuperscript{5,8}, as well as between back-healthy (BH) people and people with LBP.\textsuperscript{6,7,15} Overall the findings from these studies indicate that people with LBP move the lumbar spine more readily than other joints. Recent data indicates that the lumbar movement pattern observed during the forward trunk flexion phase of the clinical test of forward bending is similar to the lumbar movement pattern used during the reaching phase of the functional activity test of picking up an object (PUO).\textsuperscript{11} In the PUO test, people with LBP and high levels of functional limitation displayed greater lumbar excursion in the early phase of movement during the reaching phase compared to BH people and people with low levels of functional limitations. In addition, the amount of lumbar excursion in the early phase was associated with functional limitations.\textsuperscript{11} Since most functional activities are performed in the early- to mid-ranges of lumbar motion,\textsuperscript{16-18} the amount of lumbar excursion during the early phase of movement appears to be an important factor that may contribute to the functional limitations associated with LBP.

A second assumption of the KP model is that the lumbar movement pattern is used consistently across a range of functional activities.\textsuperscript{4} While people with LBP have been shown to display consistency in various aspects of the lumbar movement pattern when they perform a series of different clinical tests,\textsuperscript{4,19,20} to our knowledge, this has not been examined systematically during the performance of functional activities. A key first test of this assumption is to vary the demands of a single functional activity and examine an aspect of the lumbar movement pattern across the variations.

The primary purpose of the current study was to examine an aspect of the lumbar movement pattern in people with LBP and BH people when conditions of a functional activity test were
varied. We hypothesized that across all conditions, people with LBP and high levels of LBP-related functional limitation would consistently display greater lumbar excursion in the early phase of the reaching movement compared to BH people and people with LBP and low levels of LBP-related functional limitation. A second purpose of the study was to examine the relationship between the movement pattern during each test condition and LBP-related functional limitation. We hypothesized that the amount of lumbar excursion in the early phase of the reaching movement during each test condition would be related to a person’s LBP-related functional limitation.

3.3 Materials and Methods

3.3.1 Participants

Thirty-two people with LBP, and 16 gender-, age-, height- and weight-matched BH people participated. Inclusion criteria included aged 18 to 60 with a body mass index (BMI) ≤ 30 kg/m². LBP inclusion criteria included a duration of LBP symptoms for a minimum of 12 months and LBP symptoms present on greater than ½ the days of the year. A history of LBP was defined as LBP that resulted in (1) three or more consecutive days of altered daily activities, or work or school absence, or (2) seeking some type of health intervention (e.g., physical therapist, physician, chiropractor). BH participants were excluded if they reported a history of LBP as defined. Additional participant exclusion criteria included a history of (1) numbness or tingling below the knee, (2) previous spinal surgery, (3) spinal trauma, or (4) a specific LBP diagnosis such as scoliosis or spondylolisthesis. LBP participants with a modified Oswestry
Low Back Disability Questionnaire (mODI) score < 20% were considered to have low-functional limitation and were classified as LBP-Low. Participants with mODI scores 20% or greater were considered to have moderate- to high-functional limitation and were classified as LBP-High. All participants provided written informed consent approved by the Human Research Protection Office of Washington University in St. Louis School of Medicine prior to participating in the study.

3.3.2 Clinical Measures
All participants completed a series of self-report measures including (1) a demographic questionnaire, and (2) the Short-Form 36 Health Survey. LBP participants also completed (1) a LBP history questionnaire, (2) the numeric pain rating scale (NRS), (3) the mODI, and (4) the Fear Avoidance Beliefs Questionnaire (FABQ).

3.3.3 Laboratory Measures
Retroreflective markers were placed on predetermined landmarks of the trunk, pelvis and lower extremities (Table 3.1), and kinematic data were collected using an 8-camera, 3-dimensional motion capture system (Vicon Motion Systems, LTD, Denver, CO) with a sampling rate of 120Hz. Anthropometric measurements were obtained of each participant’s shank and trunk length, and anterior superior iliac crest (ASIS) height. Shank length was measured as the vertical distance from the floor to lateral knee joint line. Trunk length was measured as the vertical distance between the spinous process of the 7th cervical (C7) and the 1st sacral (S1) vertebrae. ASIS height was measured as the vertical distance from the floor to the ASIS. Participants performed five separate conditions of the functional activity test of Pick Up an Object (PUO) presented in random order (Figure 3.1). The standard PUO test condition involved placing a 20 x
36 x 12 cm, lightweight, container on a surface so that the top of the container was at a height equal to the participant’s shank length and a distance equal to 50% of the participant’s trunk length (Standard)\textsuperscript{11}. To vary the demands of the PUO test, four additional test conditions were performed with the container placed on a surface so that the top of the object was at specific heights and distances scaled to the person’s anthropometrics (High, Far, Low, Low-Far; Figure 3.1). For each condition, the participant began the movement from a comfortable standing position with feet pelvis-width apart. The participant was instructed to reach for, and pick up the container with both hands, and return to the starting position. Participants were given a maximum of 10 seconds to complete each movement trial, and 3 separate trials were performed for each PUO test condition.
Figure 3.1. Locations of object placement for the five different conditions of the Pick Up an Object (PUO) test. The object for the High condition was placed on a surface so that the top of the object was at a height equal to the anterior superior iliac spine (ASIS) and a distance equal to 150% of the trunk length. The object for the Standard condition was placed on a surface so that the top of the object was at a height equal to the shank length and a distance equal to 50% of the trunk length. The object for the Far condition was placed on a surface so that the top of the object was at a height equal to the shank length and a distance equal to 100% of the trunk length. The object for the Low condition was placed on a surface so that the top of the object was at a height equal to 50% of the shank length and a distance equal to 50% of the trunk length. The object for the Low-Far was placed on a surface so that the top of the object was at a height equal to 50% of the shank length and a distance equal to 100% of the trunk length.
Table 3.1. Locations of retroreflective markers.

<table>
<thead>
<tr>
<th>Marker</th>
<th>Location Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acromion*</td>
<td>Center of acromion</td>
</tr>
<tr>
<td>Manubrium</td>
<td>Superior aspect of manubrium</td>
</tr>
<tr>
<td>C7†</td>
<td>Spinous process 7th cervical vertebrae</td>
</tr>
<tr>
<td>T6†</td>
<td>½ distance from C7 to T12</td>
</tr>
<tr>
<td>T12†</td>
<td>Spinous process 12th thoracic vertebrae</td>
</tr>
<tr>
<td>L1</td>
<td>Spinous process 1st lumbar vertebrae</td>
</tr>
<tr>
<td>L3†</td>
<td>Spinous process 3rd lumbar vertebrae</td>
</tr>
<tr>
<td>L5</td>
<td>Spinous process 5th lumbar vertebrae</td>
</tr>
<tr>
<td>S1</td>
<td>½ distance measured from L5 to S2</td>
</tr>
<tr>
<td>Iliac Crest*</td>
<td>Most superior aspect of iliac crest</td>
</tr>
<tr>
<td>PSIS*</td>
<td>Most superior aspect of posterior superior iliac spine</td>
</tr>
<tr>
<td>Sacrum</td>
<td>Distal aspect of sacrum</td>
</tr>
<tr>
<td>ASIS*</td>
<td>Most prominent aspect of anterior superior iliac spine</td>
</tr>
<tr>
<td>Greater Trochanter*</td>
<td>Most superior aspect of greater trochanter</td>
</tr>
<tr>
<td>Thigh*</td>
<td>4-marker plate lateral distal aspect of thigh</td>
</tr>
<tr>
<td>Shank*</td>
<td>4-marker plate lateral distal aspect of shank</td>
</tr>
<tr>
<td>Knee*</td>
<td>Lateral and medial aspect of knee joint line</td>
</tr>
<tr>
<td>Ankle*</td>
<td>Prominent bony aspect of the lateral and medial malleoli</td>
</tr>
</tbody>
</table>

* Indicates markers were placed bilaterally
† Indicates markers were placed along the spinous process as well as at 4cm lateral to the spinous process
3.3.4 Data Processing

Kinematic data were processed using Visual 3D software (C-motion, Inc., Germantown, MD), and custom programs written in MATLAB software (MathWorks Inc., Natick, MA). Kinematic data were filtered using a 4th-order, dual-pass Butterworth filter with a cut-off frequency of 3 Hz.

The thoracic spine segment was defined by a vector from the C7 to the T12 spinous process. The lumbar spine segment was defined by a vector from the T12 to the S1 spinous process. The pelvis segment consisted of markers placed superficial to the right and left (a) ASIS, (b) posterior superior iliac spine, (c) iliac crests, and the distal aspect of the sacrum. The thigh segment was defined by a marker located superficial to the superior aspect of the greater trochanter, mid-thigh, and medial and lateral knee joint line.

Angular displacement in the sagittal plane was calculated across time for the thoracic, lumbar, and hip segments. Thoracic excursion was calculated as the displacement of the thoracic segment relative to the lumbar segment. Lumbar excursion was calculated as the displacement of the lumbar segment relative to the pelvis segment. Hip excursion was calculated as the displacement of the pelvis segment relative to the thigh segment. Trunk excursion was calculated as the combined excursion of the thoracic, lumbar, and hip segments. For each PUO trial, movement time (MT) was calculated as the time between the start of the forward trunk flexion and the point of maximal forward trunk flexion. The start of the forward trunk flexion was defined as a 1° change in trunk excursion from the initial standing position, and the stop of the forward trunk flexion was defined as the point equal to 98% of the maximal trunk flexion. Lumbar lordosis angle was calculated\textsuperscript{28, 29} in a static standing position.
3.3.5 Dependent Variables

Kinematics of the lumbar segment were examined during the reaching phase of each PUO trial from the start of motion to the stop of motion. Maximal excursion of the lumbar segment was calculated as well as excursions of the lumbar segment for the early phase (0-50\% of MT) and late phase (50-100\% of MT) of movement. An example of the kinematic output from the lumbar segment is presented in Figure 3.2. The intraclass correlation coefficient (ICC), and the standard error of the measure (SEM) were calculated for maximum and early phase lumbar excursion for the Standard test condition using the 16 BH participants from this study. The ICC values ranged from 0.89-0.97, and the SEM values ranged from 0.8° to 1.2°.

The sample size of 48 participants (16 per group) was based on an $\eta^2_{\text{partial}}$ effect size of 0.24 from a prior study that examined lumbar kinematics during a clinical test and a functional activity test.\textsuperscript{11} A total of 48 participants was determined to be sufficient to detect an interaction effect of group and test condition with a two-tailed $\alpha \leq 0.05$ and power of 0.80.
Figure 3.2. Time series data for lumbar spine excursion during the Pick Up an Object – Standard condition for (a) a typical back-healthy participant, and (b) a typical low back pain participant. The start of the forward trunk flexion and the maximal trunk flexion (stop) are indicated by the vertical lines. The start of the forward trunk flexion was identified as a 1° change in trunk excursion, and the stop of the forward trunk flexion was identified as the point equal to 98% of the maximal trunk flexion. The time between the start and stop of the forward motion is the movement time.
3.3.6 Data Analyses

All statistical analyses were performed using SPSS version 23.0 (IBM® SPSS® Statistics Inc., Chicago, IL, USA) and were two-tailed tests with the significance level set at \( p \leq .05 \). A chi-square test was used to test for differences in gender distribution. A one-way analysis of variance (ANOVA) test was used to test for differences in participant age, height, weight, and BMI. One-way ANOVA tests also were used to test for differences in lumbar lordosis angle, maximal trunk excursion, and MT for each test condition. Independent groups t-tests were used to test for differences in LBP-related characteristics between the two LBP groups. A repeated measures ANOVA test was conducted to test for the main and interaction effects of group (BH, LBP-Low, LBP-High) and test condition (High, Standard, Far, Low, Low-Far) for lumbar excursion in the early phase of MT. The Fisher’s least significant difference post-hoc test was performed when a significant interaction was obtained. Pearson product-moment correlation coefficients were calculated to index the association between lumbar excursion in the early phase of the reaching movement for each test condition and mODI score.

3.4 Results

3.4.1 Participant Characteristics

The groups did not differ in age, gender, height, weight, or BMI (Table 3.2). Compared to the LBP-Low group, the LBP-High group had a significantly greater (1) mODI \( (p<.01) \), (2) FABQ-work \( (p=.01) \), (3) FABQ-physical activity \( (p=.01) \), and (4) NRS average pain rating \( (p=.03) \) score. There were no differences among the groups for lumbar curvature angle in standing, or maximal trunk excursion or MT for any of the PUO test conditions (Table 3.3).
Table 3.2. Means (SD) for baseline descriptive statistics for all participants.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Back-healthy (n = 16)</th>
<th>LBP-Low (n = 16)</th>
<th>LBP-High (n = 16)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Participants</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female, n (%)</td>
<td>10 (63)</td>
<td>10 (63)</td>
<td>10 (63)</td>
<td>1.0</td>
</tr>
<tr>
<td>Age, y</td>
<td>37.4 (11.0)</td>
<td>38.6 (13.0)</td>
<td>36.2 (11.1)</td>
<td>.84</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.70 (.13)</td>
<td>1.71 (.11)</td>
<td>1.71 (.09)</td>
<td>.85</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>68.6 (14.6)</td>
<td>68.9 (15.6)</td>
<td>71.6 (9.6)</td>
<td>.79</td>
</tr>
<tr>
<td>BMI*, kg/m²</td>
<td>23.6 (2.4)</td>
<td>23.3 (3.3)</td>
<td>24.2 (2.3)</td>
<td>.60</td>
</tr>
<tr>
<td><strong>Low back pain</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mODI†, %</td>
<td>n/a</td>
<td>12.0 (4.4)</td>
<td>33.8 (8.7)</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Low back pain duration, y</td>
<td>n/a</td>
<td>10.9 (7.6)</td>
<td>14.5 (6.8)</td>
<td>.17</td>
</tr>
<tr>
<td>FABQ-Physical Activity subscale‡</td>
<td>n/a</td>
<td>5.4 (6.9)</td>
<td>12.6 (8.5)</td>
<td>.01</td>
</tr>
<tr>
<td>FABQ-Work subscale‡</td>
<td>n/a</td>
<td>9.8 (4.7)</td>
<td>14.7 (5.6)</td>
<td>.01</td>
</tr>
<tr>
<td>Pain intensity‖</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td>n/a</td>
<td>2.9 (1.1)</td>
<td>3.2 (0.8)</td>
<td>.37</td>
</tr>
<tr>
<td>Average (prior 7 days)</td>
<td>n/a</td>
<td>3.1 (0.8)</td>
<td>3.6 (0.6)</td>
<td>.03</td>
</tr>
<tr>
<td>Worst (prior 7 days)</td>
<td>n/a</td>
<td>5.3 (1.2)</td>
<td>5.6 (1.1)</td>
<td>.37</td>
</tr>
</tbody>
</table>

Bold font indicates significance at $p \leq 0.05$

* Body mass index
† modified Oswestry Low Back Disability Questionnaire; scores range from 0-100%
‡ Fear Avoidance Beliefs Questionnaire; scores range from 0-24 for the physical activity subscale, and 0-42 for the work subscale
‖ Scores range from 0 ("no pain") to 10 ("worst pain imaginable")
Table 3.3. Means (SD) for lumbar curvature angle in standing, and maximal trunk flexion and movement time for each condition of the functional activity test for the back-healthy group, low back pain group with < 20% modified Oswestry Low Back Disability Questionnaire score (LBP-Low), and the low back pain group with ≥ 20% modified Oswestry Low Back Disability Questionnaire score (LBP-High).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Back-healthy (n = 16)</th>
<th>LBP-Low (n =16)</th>
<th>LBP-High (n = 16)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lumbar curvature, deg</td>
<td>159.2 (7.9)</td>
<td>158.2 (6.6)</td>
<td>162.1 (5.4)</td>
<td>.53</td>
</tr>
<tr>
<td>Maximal trunk flexion, deg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>47.6 (9.1)</td>
<td>47.8 (11.4)</td>
<td>51.2 (12.7)</td>
<td>.58</td>
</tr>
<tr>
<td>Standard</td>
<td>89.5 (8.4)</td>
<td>90.0 (9.8)</td>
<td>88.6 (10.9)</td>
<td>.91</td>
</tr>
<tr>
<td>Far</td>
<td>97.9 (8.6)</td>
<td>96.0 (10.2)</td>
<td>94.7 (13.5)</td>
<td>.69</td>
</tr>
<tr>
<td>Low</td>
<td>119.7 (12.5)</td>
<td>122.3 (12.9)</td>
<td>119.5 (14.9)</td>
<td>.81</td>
</tr>
<tr>
<td>Low-Far</td>
<td>124.0 (14.7)</td>
<td>126.5 (12.2)</td>
<td>123.8 (15.2)</td>
<td>.84</td>
</tr>
<tr>
<td>Movement time, sec</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>1.02 (.16)</td>
<td>1.12 (.23)</td>
<td>1.07 (.20)</td>
<td>.41</td>
</tr>
<tr>
<td>Standard</td>
<td>1.15 (.22)</td>
<td>1.25 (.35)</td>
<td>1.24 (.27)</td>
<td>.60</td>
</tr>
<tr>
<td>Far</td>
<td>1.18 (.25)</td>
<td>1.25 (.38)</td>
<td>1.21 (.24)</td>
<td>.78</td>
</tr>
<tr>
<td>Low</td>
<td>1.33 (.29)</td>
<td>1.40 (.42)</td>
<td>1.39 (.31)</td>
<td>.84</td>
</tr>
<tr>
<td>Low-Far</td>
<td>1.29 (.23)</td>
<td>1.34 (.39)</td>
<td>1.33 (.20)</td>
<td>.90</td>
</tr>
</tbody>
</table>
3.4.2 Movement pattern consistency

There was a significant interaction of condition and group (F(4.29, 96.54) = 5.92, p < .01) for the amount of lumbar excursion in the early phase of movement. Figure 3.3 illustrates the results of the post-hoc tests indicating that, compared to the BH and LBP-Low groups, the LBP-High group displayed greater lumbar excursion in the early phase of movement for all PUO test conditions (p < .05), and the BH and LBP-Low groups did not differ for any PUO test condition (p > .05). Because FABQ subscale scores and NRS-Average scores were different for the LBP groups, we conducted separate repeated measures ANOVA tests, and obtained similar results when controlling for FABQ-PA (F(2.8,81.9) = 4.94, p < .01), FABQ-W (F(2.8,81.6) = 5.02, p < .01), and NRS-Average (F(2.8,80.1) = 3.23, p < .05).
Figure 3.3. Lumbar excursion (mean, SD) for the early phase (0-50% of movement time) of the reaching movement for each condition of the Pick Up an Object (PUO) test for the back-healthy (BH), low back pain group with < 20% modified Oswestry Low Back Disability Questionnaire score (LBP-Low), and the low back pain group with ≥ 20% modified Oswestry Low Back Disability Questionnaire score (LBP-High).

* Indicates significant difference between the LBP-High group and both the BH and LBP-Low group.
3.4.3 Association between lumbar excursion and functional limitation

Figure 3.4 illustrates that there were significant associations between mODI and lumbar excursion in the early phase of movement for the Standard ($r = 0.62$, $r^2 = 0.39$, $p < .01$), Far ($r = 0.42$, $r^2 = 0.17$, $p = .02$), Low ($r = 0.41$, $r^2 = 0.17$, $p = .02$), and Low-Far ($r = 0.46$, $r^2 = 0.21$, $p = .01$) conditions. The association between mODI and lumbar excursion in the early phase of MT was not significant for the High condition ($r = 0.28$, $r^2 = 0.12$, $p = .13$).
Figure 3.4. Scatterplots of the association between modified Oswestry Low Back Disability Questionnaire (mODI) scores (0-100%) and the early phase (0-50% of movement time) lumbar excursion (in degrees) during the reaching movement for people with low back pain for the (a) High ($r = 0.28, r^2 = 0.12, p = .13$), (b) Standard ($r = 0.62, r^2 = 0.39, p < .01$), (c) Far ($r = 0.42, r^2 = 0.17, p = .02$), (d) Low ($r = 0.41, r^2 = 0.17, p = .02$), and (e) Low-far ($r = 0.46, r^2 = 0.21, p = .01$) conditions.
Far condition early phase lumbar excursion (deg)

Low condition early phase lumbar excursion (deg)
(e)
3.5 Discussion

In examining the consistency of the lumbar movement pattern, we found people with LBP and high levels of functional limitation consistently displayed greater lumbar excursion in the early phase of movement compared to those with LBP and low levels of functional limitation and BH people. These results could not be explained by additional factors such as lumbar curvature, FABQ, or symptom intensity. Further, as hypothesized, greater lumbar excursion in the early phase of the movement was consistently associated with LBP-related functional limitation. To our knowledge, this is the first study to demonstrate that people display consistencies in an aspect of the lumbar movement pattern across variations of a functional activity test, and the movement pattern is related to LBP-related functional limitations.

Although several studies have examined lumbar kinematics during a single functional activity test,\textsuperscript{30-33} very little has been reported on the consistency of aspects of the lumbar movement pattern across multiple functional activity tests. Marras et al. reported people with LBP displayed increased cumulative spinal loading compared to BH people during a lifting task from varying heights and distances.\textsuperscript{34} Thomas et al. reported BH people displayed consistent patterns of spine-hip ratios when the target locations of a reaching test were varied.\textsuperscript{35, 36} Different from the Thomas studies, we included people with LBP with varying levels of LBP-related functional limitation, and we analyzed lumbar excursion rather than a hip-spine ratio. Our findings indicate that the lumbar spine consistently moves more readily into its available range in the reaching phase of the PUO task in people with LBP and high levels of functional limitation. Because the majority of daily functional activities are performed in the early- to mid-ranges of motion\textsuperscript{16-18}. 

[63]
the movement pattern may be a key factor contributing to concentrated tissue stress and potentially to LBP symptoms and functional limitation.\(^4,9,10\)

Other studies have reported associations ranging from \(r=0.09-0.73\) when examining functional limitation and maximal lumbar excursion during a clinical test.\(^{37-40}\) We found moderate to large\(^41\) associations between a person’s mODI score and the amount of lumbar excursion in the early phase of the reaching movement for 4 of the 5 test conditions. Our findings are consistent with a previous study that found a significant, moderate-size association between mODI and early phase lumbar excursion in the reaching movement during the PUO test.\(^{11}\) Thus, the current findings suggest that the manner in which a person moves the lumbar spine during a functional activity may contribute to the functional limitations. These findings are important because functional limitations are often the reason people with LBP seek treatment.\(^2,3\)

While our study examined variations of a single functional activity, the results provide some initial support for the proposal that people with LBP use a consistent lumbar movement pattern across a range of functional activities. Therapeutically, repeated movement during exercise is known to induce adaptations in the musculoskeletal and nervous systems.\(^4,42-47\) It could be argued that similar biological adaptations may be occurring due to repetition of movements during everyday activities, resulting in the altered movement pattern displayed by people with LBP and high levels of functional limitation. Additionally, the altered movement pattern displayed during functional activities is associated with their LBP-related limitations. A primary reason people with LBP seek care is limitations in performance of daily activities.\(^2,3\) Thus, one logical approach to treatment would be to provide challenging, repetitive practice in which the
person learns to modify the altered movement pattern within the context of performing his functional activities.

One limitation of the current study is that the standardized set-up and verbal instructions of the functional activity test may not represent the actual circumstances a person encounters during the day. Specifically, the object was placed at a location that was scaled to the individual’s anthropometrics, rather than at the same height and distance for all participants. The scaling was done, however, to eliminate participant height as a confound. A second limitation is that we examined the kinematics only during the reaching phase of the functional activity. Additional analyses should be conducted to examine aspects of the lumbar movement pattern during the return to standing phase of the functional activity. A third limitation is that the test conditions were all variations of a single activity performed in the sagittal plane. Thus, it is unknown whether people would demonstrate similar consistency in their lumbar movement pattern with activities that require movement in multiple planes.

3.6 Acknowledgements

We would like to acknowledge the contribution of Sara Putnam, who assisted with the study design, data collection, and data processing. We would also like to acknowledge members of the Musculoskeletal Analysis Laboratory for their assistance with recruitment, planning, and data processing.

This work was partially funded by the National Institutes of Health/National Institute of Child Health and Human Development/National Center for Medical Rehabilitation Research grant R01 HD047709, the Foundation for Physical Therapy; Promotion of Doctoral Studies Scholarship,
the Dr. Hans and Clara Davis Zimmerman Foundation, and the Program in Physical Therapy at Washington University School of Medicine.
3.7 Reference List


5. Gombatto SP, Collins DR, Engsberg JR, Sahrmann SA, Van Dillen LR. Patterns of lumbar region movement during trunk lateral bending in two different subgroups of people with low back pain. *Phys Ther* 2007 April;87(4):441-54.


Chapter 4. The Effects of a Single Session of Motor Skills Training on the Lumbar Movement Pattern During a Functional Activity in People With Low Back Pain

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4.1 Abstract

Objectives: To examine the ability of people with low back pain (LBP) to modify the lumbar movement pattern, and the effects on symptoms, following a single-session of motor skills training during a functional activity.

Design: Repeated-measures study in which people with LBP performed a functional activity test and participated in a single-session of motor skills training.

Setting: University musculoskeletal analysis laboratory.

Participants: Persons with chronic LBP (N=26; 15 female, 11 male), and 16 back-healthy (BH, 10 female, 6 male) people were recruited from the community.

Interventions: The lumbar movement pattern was examined during the performance of a functional activity test and following a 20-minute session of motor skills training.

Main Outcome Measures: Early-phase lumbar excursion and provocation of LBP symptoms during the functional activity test were measured pre- and post-training. Characteristics of people with LBP that influenced the ability to change following training were also examined.

Results: Prior to training, people with LBP displayed significantly more early-phase lumbar excursion compared to BH people (LBP, 11.5°±6.2°; BH, 7.1°±2.7°, p < .01). Following training, the LBP group demonstrated a significant decrease in early-phase lumbar excursion (4.1°±4.4°, p < .01). Eleven people with LBP reported increased symptoms with the functional activity test prior to training, and 91% reported improvement in symptoms following training. The amount of early-phase lumbar excursion pre-training, and the duration of LBP symptoms...
were significant predictors in the ability to modify the lumbar movement pattern.

**Conclusion:** Motor skills training may be an effective approach to modifying the lumbar movement pattern and reducing LBP symptoms during a functional activity.

**Key words:** Low back pain, functional limitation, functional activity, motor skills
4.2 Introduction

Low back pain (LBP) is the leading cause of non-fatal disability worldwide,\textsuperscript{1-3} often resulting in persistent pain and limitations in the performance of daily functional activities.\textsuperscript{4, 5} The primary reason people with LBP seek initial and repeated medical care for a LBP problem is limitations in the performance of functional activities.\textsuperscript{6, 7} While exercise has been shown to be an effective approach for the treatment of chronic LBP, no specific form of exercise has been shown to be most effective for improving LBP-related functional limitations.\textsuperscript{8-11} One possible explanation may be that the exercise treatments have not focused on identifying and modifying movement patterns used repeatedly throughout the day.

During clinical tests of movement, the lumbar movement pattern frequently identified in people with LBP has been one in which the lumbar spine moves more readily into its available range of motion compared to other joints that contribute to the overall movement (e.g., hip or thoracic spine).\textsuperscript{12-15} This movement pattern of early lumbar motion is proposed to contribute to the development and course of low back pain.\textsuperscript{12} Since most functional activities are performed in the early- to mid-ranges of lumbar motion,\textsuperscript{16-18} repeatedly using a movement pattern of early lumbar motion could lead to repetitive microtrauma and eventually symptoms.\textsuperscript{12, 19, 20} Recent data suggests that people with LBP and high functional limitations consistently display a pattern of early lumbar motion during functional activity tests.\textsuperscript{21} Additional research suggests that the pattern of early lumbar motion is associated with a persons’ LBP symptoms \textsuperscript{22-25} and functional limitations.\textsuperscript{21, 26} Therefore, treatment directed at decreasing the amount of early lumbar motion during a functional activity may be a logical approach to improving symptoms and functional limitations in people with chronic LBP.
Prior research has demonstrated that people with LBP can reduce the amount of early lumbar motion during a clinical test. Modifying the lumbar movement pattern during clinical tests has been shown to be an effective process to reduce LBP symptoms and functional limitations. Given the significance of limitations in functional activities for people with LBP, it would be important to examine the (1) ability to modify the lumbar movement pattern during a functional activity, (2) effect of modifying the movement pattern on LBP symptoms, and (3) characteristics of people that influence the ability to modify the pattern.

The primary purpose of the current study was to examine the ability of people with LBP to reduce the amount of early lumbar motion during a functional activity test within a single session of motor skills training (MST). The MST involved challenging practice to facilitate learning to modify a functional activity often painful and limited for people with LBP. We hypothesized that following MST, people with LBP would demonstrate decreased early lumbar motion during the functional activity test. A secondary purpose was to examine the effect of modifying the lumbar movement pattern on LBP symptoms. We hypothesized that decreasing the amount of early lumbar motion would result in an improvement in LBP symptoms during the functional activity test. The final purpose of this study was to examine characteristics of people with LBP that were associated with the ability to minimize the early lumbar motion when performing the functional activity. We hypothesized that certain demographic, hamstring extensibility and lumbar alignment, LBP, and movement characteristics would be associated with the change in early-phase lumbar motion following training. Improved understanding of the characteristics that are associated with the performance of a specific task following instruction may be an important component of determining a treatment intervention.

[75]
4.3 Methods

Twenty-six people with LBP were recruited through advertisements in the St. Louis metropolitan area. In order to compare the preferred movement pattern, 16 gender-, age-, height, and weight-matched BH people also were recruited. Inclusion and exclusion criteria are listed in Table 4.1. All participants signed a written informed consent approved by the Washington University School of Medicine Human Research Protection Office.
Table 4.1. Inclusion and exclusion criteria for participants with low back pain (LBP) and back-healthy (BH) participants.

<table>
<thead>
<tr>
<th>Inclusion criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>All participants</td>
</tr>
<tr>
<td>Age 18-60</td>
</tr>
<tr>
<td>Body mass index &lt;30kg/m²</td>
</tr>
<tr>
<td>LBP Participants</td>
</tr>
<tr>
<td>History of LBP*</td>
</tr>
<tr>
<td>LBP symptoms for at least 12 months duration</td>
</tr>
<tr>
<td>LBP symptoms present on greater than ½ the days of the year</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exclusion criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>BH Participants</td>
</tr>
<tr>
<td>History of LBP*</td>
</tr>
<tr>
<td>All Participants</td>
</tr>
<tr>
<td>Spinal complications (i.e., tumor or infection)</td>
</tr>
<tr>
<td>Previous spinal surgery (lumbar)</td>
</tr>
<tr>
<td>Neurological disease requiring hospitalization</td>
</tr>
<tr>
<td>Diagnosis of any of the following spinal conditions:</td>
</tr>
<tr>
<td>Marked kyphosis/ scoliosis</td>
</tr>
<tr>
<td>Spinal stenosis</td>
</tr>
<tr>
<td>Spondylolisthesis</td>
</tr>
<tr>
<td>Spinal instability</td>
</tr>
<tr>
<td>Spinal fracture or dislocations</td>
</tr>
<tr>
<td>Osteoporosis</td>
</tr>
<tr>
<td>Ankylosing spondylitis</td>
</tr>
<tr>
<td>Disc herniation with current radicular symptoms</td>
</tr>
<tr>
<td>Rheumatoid arthritis</td>
</tr>
<tr>
<td>Currently pregnant</td>
</tr>
<tr>
<td>Undergoing treatment for kidney or bladder infection</td>
</tr>
<tr>
<td>Loss of sensation, weakness, or numbness in arms or legs</td>
</tr>
<tr>
<td>Pain, numbness, or tingling below the knees</td>
</tr>
<tr>
<td>Difficulty standing or walking without assistance</td>
</tr>
<tr>
<td>Undergoing treatment for cancer</td>
</tr>
<tr>
<td>Receiving disability benefits or worker’s compensation for LBP</td>
</tr>
<tr>
<td>Involved in litigation for LBP</td>
</tr>
</tbody>
</table>

*A history of LBP was defined as LBP symptoms that resulted in (1) seeking medical/healthcare intervention (e.g., physician, chiropractor, physical therapist), or (2) altered performance of work, school, daily functional or physical activity for 3 or more consecutive days.
4.3.1 Self-report measures

Following consent, all participants completed a survey of demographic information and the Short Form 36 Health Survey (SF-36). Participants with LBP also completed self-report surveys including (1) a LBP history questionnaire, (2) the numeric pain rating scale (NRS), (3) the modified Oswestry Low Back Disability Questionnaire (mODI), and (4) the Fear Avoidance Beliefs Questionnaire (FABQ). All participants were assessed by a trained physical therapist for hamstring extensibility using the Hamstring Length and Associated Lumbar Flexibility test (HS length).

4.3.2 Laboratory measures

An 8-camera, 3-dimensional motion capture system (Vicon Motion Systems, LTD, Denver, CO) with a sampling rate of 120 Hz was used to capture kinematic data. Retroreflective markers were placed on predetermined landmarks of the lower extremities, pelvis, and trunk (Table 4.2). Participants were instructed to stand in a comfortable position with feet placed pelvis-width apart. Participants performed three separate movement trials for two conditions of the functional activity test of Pick Up an Object (PUO). For both PUO test conditions, a 20x30x12cm, lightweight, container was placed at a height equal to the participant’s shank length, and at a distance equal to the participant’s trunk length. Participants received verbal instructions to pick up the object using both hands and return to the starting position. A maximum of 10 seconds was allowed to complete each movement trial, and participants were instructed to move at a self-selected speed. Participants with LBP reported whether their symptoms increased, decreased, or remained the same during the movement compared to their symptoms in standing. For the first PUO test condition, participants were not provided any instruction regarding how to move, and
the movement was considered to be the participant’s preferred movement pattern (PUO-Preferred). Upon completion of the PUO-Preferred movement trials, participants with LBP underwent a 20-minute session of MST by a trained physical therapist (Appendix). The MST focused on decreasing the amount of early-phase lumbar excursion, and increasing the amount of early-phase hip movement with the functional activity. The MST included demonstration, visual cues, tactile cues, and opportunity for practice with both internal and external feedback.\textsuperscript{40}

Participants then performed 3 separate trials of the second PUO functional activity test condition (PUO-MST).

A 4\textsuperscript{th}-order, dual-pass Butterworth filter with a cut-off frequency of 3 Hz was applied, and the kinematic data were processed using Visual 3D software (C-motion, Inc., Germantown, MD), and MATLAB (MathWorks Inc., Natick, MA) custom written software. The lumbar curvature angle was calculated in standing.\textsuperscript{41, 42} A vector between the C7 marker and the T12 marker defined the thoracic segment. A vector between the T12 and S1 marker defined the lumbar segment. Markers placed on the right and left (a) posterior superior iliac spine, (b) iliac crest, (c) anterior superior iliac spine, and the distal sacrum defined the pelvis segment. Markers on the mid-thigh, greater trochanter, and the medial- and lateral-knee joint line defined the thigh segment.

Sagittal plane angular displacements of the thoracic, lumbar, pelvis, and thigh segments were calculated from the start of motion to the stop of motion for both test conditions. Excursion of the thoracic spine was calculated relative to the lumbar segment. Excursion of the lumbar spine was calculated relative to the pelvis segment. Excursion of the hip was calculated as the angular displacement of the pelvis segment relative to the thigh segment. Trunk excursion was defined as
the angular displacement of the combined thoracic, lumbar, and hip segments. The start of motion was defined as a 1° change in sagittal plane trunk excursion. The stop of motion was defined as 98% of the maximum trunk excursion. Movement time (MT) was calculated, and increments of MT were determined for the first 50% (early-phase) and last 50% (late-phase) of MT. Intraclass correlation coefficients (ICC) and standard error of the measure (SEM) were calculated for the 16 BH participants during the PUO-Preferred test for maximal, early-phase, and late-phase lumbar excursion. ICC[3,1] values ranged from 0.88-0.95, with SEM values ranging from 0.8°-1.2°.
<table>
<thead>
<tr>
<th>Marker</th>
<th>Location Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acromion*</td>
<td>Center of acromion</td>
</tr>
<tr>
<td>Manubrium</td>
<td>Superior aspect of manubrium</td>
</tr>
<tr>
<td>C7†</td>
<td>Spinous process of 7th cervical vertebrae</td>
</tr>
<tr>
<td>T6†</td>
<td>½ distance from C7 to T12</td>
</tr>
<tr>
<td>T12†</td>
<td>Spinous process 12th thoracic vertebrae</td>
</tr>
<tr>
<td>L1</td>
<td>Spinous process 1st lumbar vertebrae</td>
</tr>
<tr>
<td>L3†</td>
<td>Spinous process 3rd lumbar vertebrae</td>
</tr>
<tr>
<td>L5</td>
<td>Spinous process 5th lumbar vertebrae</td>
</tr>
<tr>
<td>S1</td>
<td>½ distance measured from L5 to S2</td>
</tr>
<tr>
<td>Iliac Crest*</td>
<td>Most superior aspect of iliac crest</td>
</tr>
<tr>
<td>PSIS*</td>
<td>Most superior aspect of posterior superior iliac spine</td>
</tr>
<tr>
<td>Sacrum</td>
<td>Distal aspect of sacrum</td>
</tr>
<tr>
<td>ASIS*</td>
<td>Most prominent aspect of anterior superior iliac spine</td>
</tr>
<tr>
<td>Greater Trochanter*</td>
<td>Most superior aspect of greater trochanter</td>
</tr>
<tr>
<td>Thigh*</td>
<td>4-marker plate lateral distal aspect of thigh</td>
</tr>
<tr>
<td>Shank*</td>
<td>4-marker plate lateral distal aspect of shank</td>
</tr>
<tr>
<td>Knee*</td>
<td>Lateral and medial aspect of knee joint line</td>
</tr>
<tr>
<td>Ankle*</td>
<td>Prominent bony aspect of the lateral and medial malleoli</td>
</tr>
</tbody>
</table>

* Indicates markers were placed bilaterally
† Indicates markers were placed along the spinous process as well as at 4cm lateral to the spinous process
4.3.3 Dependent variables
Lumbar and hip kinematics were examined for the PUO-Preferred and PUO-MST tests, and the primary variable of interest was the early-phase lumbar excursion. Change in early-phase lumbar excursion for the LBP group was calculated by subtracting the early-phase lumbar excursion during the PUO-MST test from the PUO-Preferred test.

4.3.4 Data analyses
Statistical analyses were performed using SPSS version 23.0 (IBM® SPSS® Statistics Inc., Chicago, IL, USA), with a two-tailed significance level set at $p \leq .05$. The sample size of 26 LBP participants was calculated based on data from a previous study that reported a 2.8 degree within-session change in lumbar excursion during a clinical test.27

4.3.4.1 Participant characteristics
Differences in relevant participant characteristics between the groups were examined using a Chi-square test or independent groups t-test.

4.3.4.2 Movement excursion
Independent groups t-tests were conducted to examine differences between the BH and LBP groups for MT, maximal lumbar and hip excursion, and early-phase lumbar excursion during the PUO-Preferred test. Next, a paired samples t-test was conducted to examine the change in early-phase lumbar excursion between the PUO-Preferred and the PUO-MST conditions for the LBP group. Finally, an independent groups t-test was used to examine differences in the early-phase lumbar excursion between the BH group (PUO-Preferred) and the LBP group following MST
A Bonferroni correction was applied to account for the multiple comparisons (n=3) of the early-phase lumbar excursion variable; $\alpha \leq .017$ was required for significance.

4.3.4.3 Symptoms with movement

A McNemar’s test was conducted to test for differences in the proportion of participants who reported an increase in LBP symptoms during the PUO-Preferred test, but not during the PUO-MST test. Independent groups t-tests were conducted on baseline participant characteristics between participants who reported an increase in symptoms during the PUO-Preferred test, and those who did not.

4.3.4.4 Factors associated with change in early-phase lumbar excursion

For people with LBP, a linear regression analysis was conducted to predict the criterion variable; change in early-phase lumbar excursion. Pearson product-moment correlation coefficients were calculated between the criterion variable and the characteristics in Table 3, as well as the PUO-Preferred early-phase lumbar excursion. Bivariate correlations also were calculated among the predictor variables that were correlated significantly ($p<.05$) with the criterion variable to assist in determining the choice of predictor variables to be included in the linear regression analysis.

4.4 Results

4.4.1 Participant characteristics

The groups were not different in baseline characteristics. There were no differences between the BH and LBP group in initial lumbar curvature angle in standing, or hamstring extensibility ($p>.05$; Table 4.3).
Table 4.3. Descriptive statistics presented as the mean (SD) unless otherwise noted, statistical value, and probability value of baseline characteristics of the back-healthy (BH) participants, and participants with low back pain (LBP)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>BH (n = 16)</th>
<th>LBP (n =26)</th>
<th>Statistical value</th>
<th>Probability value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Demographics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female, n (%)</td>
<td>10 (63)</td>
<td>15 (58)</td>
<td>$\chi^2 = 1.17$</td>
<td>.76</td>
</tr>
<tr>
<td>Age, y</td>
<td>37.4 (11.0)</td>
<td>38.5 (12.3)</td>
<td>$t = 0.27$</td>
<td>.79</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.70 (.13)</td>
<td>1.72 (.10)</td>
<td>$t = 0.65$</td>
<td>.52</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>68.6 (14.6)</td>
<td>71.9 (11.6)</td>
<td>$t = 0.80$</td>
<td>.43</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>23.6 (2.4)</td>
<td>24.0 (2.6)</td>
<td>$t = 0.54$</td>
<td>.59</td>
</tr>
<tr>
<td><strong>Extensibility and alignment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HS length test*, deg</td>
<td>166.4 (7.6)</td>
<td>167.3 (8.2)</td>
<td>$t = 0.36$</td>
<td>.72</td>
</tr>
<tr>
<td>Lumbar lordosis angle †, deg</td>
<td>161.2 (7.7)</td>
<td>158.9 (6.8)</td>
<td>$t = 0.86$</td>
<td>.33</td>
</tr>
<tr>
<td><strong>Low back pain</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mODI ‡, %</td>
<td>24.2 (12.8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low back pain duration, y</td>
<td>13.7 (7.5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FABQ-W †</td>
<td>12.5 (5.6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FABQ-PA †</td>
<td>9.3 (8.6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pain intensity§</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td>3.0 (1.0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average (prior 7 days)</td>
<td>3.4 (0.8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Worst (prior 7 days)</td>
<td>5.4 (1.2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF-36 PCS¶</td>
<td>84.7 (14.5)</td>
<td>80.6 (13.9)</td>
<td>$t = 0.92$</td>
<td>.37</td>
</tr>
<tr>
<td>SF-36 MCS¶</td>
<td>78.8 (14.9)</td>
<td>72.8 (16.0)</td>
<td>$t = 1.21$</td>
<td>.23</td>
</tr>
</tbody>
</table>

*Hamstring length and associated lumbar flexibility test was conducted in supine with tested leg placed in 90° of hip flexion, and inclinometer aligned with the long axis of the fibula.
† Calculated as $2\arctan(0.5l/d)$, where $l$ is the vertical distance from the L1 to L5 marker, and $d$ is the distance perpendicular from a vector from L3 to $l$.
‡ modified Oswestry Low Back Disability Questionnaire; scores range from 0-100%
§ Scores range from 0 (“no pain”) to 10 (“worst pain imaginable”)
¶ The Short Form-36 questionnaire; scores range from 0-100 for the physical health component (PCS) and the mental health component (MHS) subscales
4.4.2 Movement excursion

Mean MT and maximal lumbar and hip segment excursion for the two PUO conditions are presented in Table 4.4. Figure 4.1 represents the early-phase lumbar excursion for the PUO-Preferred test for both groups, and the PUO-MST test for the LBP group. In the PUO-Preferred condition, the LBP group displayed significantly greater early-phase lumbar excursion (11.5° ± 6.2°) compared to the BH group (7.1° ± 2.7°; \( t = -2.95, \ p < .01 \)). Following MST, the LBP group demonstrated a significant decrease in early-phase lumbar excursion (4.1° ± 4.4°; \( t = 4.73, \ p < .01 \)) compared to their movement in the PUO-Preferred condition. Following MST, the early-phase lumbar excursion of the LBP group was not different from the PUO-Preferred condition of the BH group (0.09° ± 0.51°, \( t = 0.11, \ p = .91 \)).
Table 4.4. Means, standard deviations, statistical and probability values for movement time and maximal excursion for the lumbar and hip segment excursions for the Pick Up an Object test for the preferred (PUO-Preferred) condition for the back-healthy (BH) group and the low back pain (LBP) group. Means and standard deviations for the Pick Up an Object test following motor skills training for the LBP group (PUO-MST) with probability values in reference to the PUO-Preferred test for the BH group.

<table>
<thead>
<tr>
<th></th>
<th>BUO-Preferred</th>
<th></th>
<th></th>
<th>PUO-MST</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BH</td>
<td>LBP</td>
<td>t-statistic</td>
<td>p-value</td>
<td>BH</td>
<td>LBP</td>
</tr>
<tr>
<td>Movement time (s)</td>
<td>1.19 (0.24)</td>
<td>1.23 (0.30)</td>
<td>0.46</td>
<td>.64</td>
<td>1.47 (0.38)</td>
<td>1.14</td>
</tr>
<tr>
<td>Maximal excursion, deg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lumbar</td>
<td>18.6 (7.7)</td>
<td>18.5 (5.8)</td>
<td>0.09</td>
<td>.93</td>
<td>16.2 (6.2)</td>
<td>1.16</td>
</tr>
<tr>
<td>Hip</td>
<td>52.2 (11.0)</td>
<td>49.7 (13.3)</td>
<td>0.63</td>
<td>.53</td>
<td>57.0 (15.4)</td>
<td>1.10</td>
</tr>
</tbody>
</table>
Figure 4.1. Change in early-phase lumbar excursion following motor skills training. Mean and SD values for early-phase lumbar excursion for the back-healthy (BH) people during the Pick Up an Object (PUO) test for the preferred condition, and for people with low back pain (LBP) during the Pick Up an Object test for the preferred and motor skills training (MST) condition. Significant effects are indicated with symbols. There was no difference between the Preferred condition for the BH group and the MST condition for the LBP group.

* Indicates a significant difference between the BH and LBP groups for the PUO-Preferred condition.
† Indicates a significant change in early-phase lumbar excursion between the PUO-Preferred and PUO-MST conditions for the LBP group.
4.4.3 Symptoms with movement

Forty-two percent (11/26) of LBP participants reported an increase in symptoms during the PUO-Preferred test. Following MST, 91% of these participants no longer reported an increase in LBP symptoms during the PUO-MST test ($p < .01$). Baseline characteristics of the groups are presented in Table 4.5.
Table 4.5. Descriptive statistics presented as the mean (SD) unless otherwise noted, statistical value, and probability value of baseline characteristics for participants with low back pain who reported an increase in symptoms, and participants who reported no increase in symptoms during the PUO-Preferred test.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Increase in symptoms</th>
<th>No increase in symptoms</th>
<th>Statistical value</th>
<th>Probability value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Demographics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female, n (%)</td>
<td>5 (45)</td>
<td>10 (67)</td>
<td>$X^2 = 1.17$</td>
<td>.25</td>
</tr>
<tr>
<td>Age, y</td>
<td>37.1 (12.2)</td>
<td>39.5 (12.8)</td>
<td>$t = 0.48$</td>
<td>.64</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.73 (0.10)</td>
<td>1.73 (0.10)</td>
<td>$t = 0.02$</td>
<td>.98</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>71.3 (7.4)</td>
<td>72.4 (14.2)</td>
<td>$t = 0.24$</td>
<td>.82</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>23.9 (1.8)</td>
<td>24.1 (3.1)</td>
<td>$t = 0.20$</td>
<td>.84</td>
</tr>
<tr>
<td><strong>Extensibility and alignment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HS length test*, deg</td>
<td>164.0 (9.7)</td>
<td>169.7 (6.2)</td>
<td>$t = 1.80$</td>
<td>.08</td>
</tr>
<tr>
<td>Lumbar lordosis angle†, deg</td>
<td>159.4 (4.7)</td>
<td>161.4 (4.9)</td>
<td>$t = 0.61$</td>
<td>.54</td>
</tr>
<tr>
<td><strong>Low back pain</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mODI‡, %</td>
<td>29.5 (10.4)</td>
<td>20.4 (13.4)</td>
<td>$t = 1.86$</td>
<td>.08</td>
</tr>
<tr>
<td>Low back pain duration, y</td>
<td>13.9 (6.8)</td>
<td>13.6 (8.2)</td>
<td>$t = 0.10$</td>
<td>.92</td>
</tr>
<tr>
<td>FABQ-W‖</td>
<td>15.5 (6.4)</td>
<td>10.2 (3.6)</td>
<td>$t = 2.70$</td>
<td>.01</td>
</tr>
<tr>
<td>FABQ-PA‖</td>
<td>14.5 (8.1)</td>
<td>5.5 (6.9)</td>
<td>$t = 3.03$</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Pain intensity§</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td>3.3 (1.0)</td>
<td>2.9 (1.0)</td>
<td>$t = 1.03$</td>
<td>.32</td>
</tr>
<tr>
<td>Average (prior 7 days)</td>
<td>3.5 (0.7)</td>
<td>3.3 (0.8)</td>
<td>$t = 0.93$</td>
<td>.36</td>
</tr>
<tr>
<td>Worst (prior 7 days)</td>
<td>5.7 (1.4)</td>
<td>5.1 (1.0)</td>
<td>$t = 1.26$</td>
<td>.22</td>
</tr>
<tr>
<td>SF-36 PCS¶</td>
<td>78.6 (15.8)</td>
<td>82.0 (12.6)</td>
<td>$t = 0.60$</td>
<td>.55</td>
</tr>
<tr>
<td>SF-36 MCS¶</td>
<td>65.8 (18.6)</td>
<td>77.9 (11.9)</td>
<td>$t = 2.02$</td>
<td>.06</td>
</tr>
<tr>
<td><strong>Movement</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximal lumbar excursion, deg</td>
<td>19.8 (4.6)</td>
<td>17.5 (6.5)</td>
<td>$t = 0.99$</td>
<td>.33</td>
</tr>
<tr>
<td>Early-phase lumbar excursion, deg</td>
<td>13.2 (3.2)</td>
<td>9.6 (5.6)</td>
<td>$t = 1.89$</td>
<td>.07</td>
</tr>
<tr>
<td>Maximal hip excursion, deg</td>
<td>46.4 (9.8)</td>
<td>52.1 (15.3)</td>
<td>$t = 1.08$</td>
<td>.29</td>
</tr>
</tbody>
</table>

Bold face indicates significance ($p<.05$)
*Hamstring length and associated lumbar flexibility test was conducted in supine with tested leg placed in 90° of hip flexion, and inclinometer aligned with the long axis of the fibula.
†Calculated as $2\arctan(0.5l/d)$, where $l$ is the vertical distance from the L1 to L5 marker, and $d$ is the distance perpendicular from a vector from L3 to $l$
‡modified Oswestry Low Back Disability Questionnaire; scores range from 0-100%
‖Fear Avoidance Beliefs Questionnaire; scores range from 0-42 for the work subscale (FABQ-W), and 0-24 for the physical activity subscale (FABQ-PA)
§Scores range from 0 (“no pain”) to 10 (“worst pain imaginable”)
¶The Short Form-36 questionnaire; scores range from 0-100 for the physical health component (PCS) and the mental health component (MHS) subscores
4.4.4 Variables associated with the change in early-phase lumbar excursion

The variables that were correlated significantly with change in early-phase lumbar excursion, included (1) HS length ($r = -0.52$, $r^2 = 0.27$, $p < .01$), (2) mODI score ($r = 0.57$, $r^2 = 0.33$, $p < .01$), (3) duration of LBP symptoms ($r = 0.39$, $r^2 = 0.16$, $p = .05$), and (4) PUO-Preferred early-phase lumbar excursion ($r = 0.88$, $r^2 = 0.78$, $p < .01$; Table 4.6). With a sample size of 26 participants, three variables could be entered into the linear regression analysis. The mODI score data was not included in the regression model because it was highly correlated with PUO-Preferred early-phase lumbar excursion. Additionally, mODI scores previously have been shown to be associated with the amount of early-phase lumbar excursion in a PUO-Preferred condition\textsuperscript{21,26} Thus, the regression analysis included (1) PUO-Preferred early-phase lumbar excursion, (2) HS length, and (3) duration of LBP symptoms. The three-variable model accounted for 82.1\% of the variance in the change in early-phase lumbar excursion ($F = 33.70$, $p < 0.01$; Table 4.7). The PUO-Preferred early-phase lumbar excursion ($\beta = -0.82$, $p < .01$) and duration of LBP symptoms ($\beta = -0.22$, $p = .03$) were the only significant predictors in the regression model.
Table 4.6. Pearson product moment correlation coefficients of select characteristics of people with low back pain that are significantly correlated with the criterion variable; change in early-phase lumbar excursion.

<table>
<thead>
<tr>
<th>Change in early-phase lumbar excursion</th>
<th>PUO-Preferred early-phase lumbar excursion</th>
<th>mODI</th>
<th>Duration of LBP symptoms</th>
<th>HS length test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in early-phase lumbar excursion</td>
<td>0.88</td>
<td>0.57</td>
<td>0.39</td>
<td>-0.52</td>
</tr>
<tr>
<td>PUO-Preferred early-phase lumbar excursion</td>
<td>0.88</td>
<td>0.65</td>
<td>0.21</td>
<td>-0.60</td>
</tr>
<tr>
<td>mODI*</td>
<td>0.57</td>
<td>0.65</td>
<td>0.11</td>
<td>-0.44</td>
</tr>
<tr>
<td>Duration of LBP symptoms</td>
<td>0.39</td>
<td>0.21</td>
<td>0.11</td>
<td>-0.02</td>
</tr>
<tr>
<td>HS length test†</td>
<td>-0.52</td>
<td>-0.60</td>
<td>-0.44</td>
<td>-0.02</td>
</tr>
</tbody>
</table>

Bold font indicates significant correlation \( p < .05 \)
* modified Oswestry Low Back Disability Questionnaire (0-100%)
† Hamstring length and associated lumbar flexibility test was conducted in supine with tested leg placed in 90° of hip flexion, and inclinometer aligned with the long axis of the fibula, and the non-tested leg placed in a position of hip and knee flexion with the foot flat on the table.
Table 4.7. Results of the standard multiple regression analysis examining predictors of change in early-phase lumbar excursion for people with low back pain (LBP).

<table>
<thead>
<tr>
<th>Predictor variables</th>
<th>$R^2$</th>
<th>$p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PUO-Preferred early-phase lumbar excursion*</td>
<td>0.78</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Duration of LBP symptoms</td>
<td>0.05</td>
<td>.03</td>
</tr>
<tr>
<td>HS length test†</td>
<td>0.00</td>
<td>.86</td>
</tr>
<tr>
<td>Total $R^2$</td>
<td>0.82</td>
<td>&lt;.01</td>
</tr>
</tbody>
</table>

* Amount of early-phase lumbar excursion (deg) during the Pick Up an Object test.
† Hamstring length and associated lumbar flexibility test was conducted in supine with tested leg placed in 90° of hip flexion, and inclinometer aligned with the long axis of the fibula, and the non-tested leg placed in a position of hip and knee flexion with the foot flat on the table.
4.5 Discussion

The first purpose of this study was to examine if people with LBP could modify their preferred lumbar movement pattern during a functional activity test. We found that following training, participants with LBP were able to reduce the amount of early-phase lumbar excursion, and displayed a pattern of lumbar excursion similar to the pattern displayed by BH participants. The second purpose of this study was to examine the effect of MST on LBP symptoms during a functional activity. Consistent with our hypothesis, 91% of participants with increased LBP symptoms during the preferred movement reported decreased LBP symptoms following training. Therefore, modifying the lumbar movement pattern was an effective approach to improving LBP symptoms. The final purpose of this study was to examine which characteristics of people with LBP were associated with the ability to modify their preferred pattern of lumbar excursion during the activity test. We found that a person’s preferred movement pattern, and how long the person had LBP symptoms were associated with the ability to change his preferred movement pattern during the test. Overall, the more early-phase lumbar excursion a person displayed during the preferred movement condition, and the longer the person had LBP, the more a person could change after MST.

Immediately after a 20-minute session of MST, people with LBP were able to reduce the amount of early-phase lumbar excursion during a functional activity test. Two previous studies have documented that following (1) a single session, and (2) 6-weeks of training, people with LBP were able to modify their preferred lumbar movement pattern during a clinical test.\textsuperscript{27,28} In a separate study, people with LBP demonstrated the ability to modify the lumbar movement pattern during a series of clinical tests following training to improve movement control.\textsuperscript{29}
Different from the prior studies we were interested in whether people with LBP could modify their preferred lumbar movement pattern during a functional activity test. The test we chose was one that mimics a functional activity found to be problematic for many people with LBP. To our knowledge, our study is the first to demonstrate the ability of people with LBP to modify the lumbar movement pattern during a functional activity test.

Prior research has reported that during clinical tests, people with LBP (1) display a lumbar movement pattern of early lumbar motion, and (2) report an immediate improvement in LBP symptoms when the lumbar spine is manually stabilized to reduce early lumbar motion. Similar to prior research, we also found that reducing early lumbar motion improved LBP symptoms. However, different from the previous studies, we observed that people with LBP displayed early lumbar motion during a functional activity, and were able to modify the movement pattern on their own. The results of the current study are important because we were able to quantify the ability of people with LBP to modify the lumbar movement pattern, and demonstrate that modifying the movement pattern resulted in improved symptoms.

Because not all people with LBP respond similarly to a given treatment we wanted to know what participant characteristics were associated with the ability to modify the movement pattern. When we looked at simple correlations, we found that the ability to reduce the early-phase lumbar excursion was significantly associated with the amount of early-phase lumbar excursion during the preferred movement, mODI scores, duration of LBP symptoms, and hamstring extensibility. We did not include the mODI score variable in the final regression analysis because in prior research, as well as in the current study, mODI scores were found to be significantly associated with the amount of early-phase lumbar excursion during the PUO test.

[94]
Thus, the information provided by the two variables was highly redundant. When the remaining variables were entered into the regression analysis, only early-phase lumbar excursion during the preferred condition and duration of LBP were significant predictors of the change in early-phase lumbar excursion. The results of our regression analysis may seem counter-intuitive because one might assume that people with a longer duration of symptoms and more impaired movement would have difficulty modifying the movement pattern. Our results, however, are encouraging because they suggest even people that are more impaired are still able to modify their lumbar movement pattern after training.

4.5.1 Study limitations

One potential limitation is that the set-up and verbal instructions for the PUO test were standardized, and may not reflect the actual circumstances encountered during performance of daily activities. First, the placement of the object used in the PUO test was scaled to the person, rather than set to a constant position. The rationale for scaling the placement of the object to the individual was to decrease the likelihood of differences in movement time and total excursion due to variations in participant height. Additionally, the participants were instructed not to move their feet, and to retrieve the object using both hands. While the standardizations may not represent the exact manner in which a person would perform this activity outside of a laboratory setting, they provide an avenue to examine the lumbar movement pattern. A second potential limitation is that the primary variable of interest, change in early-phase lumbar excursion, was examined following only one session of training. It is unknown, however, whether the improved movement pattern would be retained beyond the session. Finally, it is unknown whether the MST applied during a single functional activity would translate to changes observed under more
variable conditions of the activity or during other unrelated functional activities. Therefore, future work should examine the ability to modify the preferred lumbar movement pattern during additional functional activities. The retention and generalization of the modified lumbar movement pattern to performance of different activities also should be examined.

4.6 Conclusions

Our findings suggest that people with LBP can modify their preferred lumbar movement pattern within a single session of MST during a functional activity test. Following the MST, people with LBP displayed decreased lumbar excursion in the early-phase of the test movement, and decreased LBP symptoms with the functional activity. The person’s preferred movement pattern during the PUO test and duration of LBP symptoms were associated with a person’s ability to modify his preferred lumbar movement pattern.
4.7 Reference List


[99]


4.8 APPENDIX

Description of the motor skills training protocol used during the Pick Up an Object (PUO) functional activity test.

Following the completion of the PUO test, the participant was provided with a 20-minute session of motor skills training, with the primary objectives of (1) identifying the participant’s preferred movement strategy, (2) problem-solving with participant to develop a modified movement strategy, (3) assisting the participant to identify the modified movement strategy, and (4) guided practice of the modified movement strategy. The motor skills training was designed using the principles of motor learning, specifically through promoting the use of intrinsic feedback, purposeful task practice, solving motor problems, and engaging the participant in the process. External feedback, in the form of visual or tactile cues, was minimized in order to promote the development of intrinsic feedback from the participant’s sensory systems. The progression of the motor skills training is described below. Following the description, a flow-diagram that was used during the session to assist the instructor is provided.

Motor skills training progression

Step 1) Identify the preferred movement strategy

At the start of the session, the participant was provided a brief description of the lumbar movement pattern observed during his performance of the PUO activity. The participant was informed that he was moving the lumbar spine more readily into its available motion than other joints (e.g., hip) that could contribute to the PUO movement. The participant was then instructed to perform the PUO activity as he normally would. During the movement the participant was asked to pay attention to the movement of the lumbar spine. After several repetitions, the participant was then asked if he was able to identify his preferred movement pattern, and if he could feel his lumbar spine moving during the activity. If the participant was able to feel the lumbar spine moving during the PUO activity, he was then asked to identify what specific physical attributes he felt that let him know the lumbar spine was moving. For example, the participant may have identified an increase in LBP symptoms, or tension in the lumbar region. An example of the prompting between the instructor and participant was as follows:

Instructor: *This time when you perform the movement, I want you to focus on what you feel that lets you know that you are moving your low back too soon.*
Participant performs several trials without interruption.
Instructor: *Were you able to feel your low back moving too soon during those movements?*
Participant: *I think so.*
Instructor: *What did you feel during the movement that lets you know you were moving too soon in the low back?*

Participant: *I felt my usual back pain when I started moving.*

If the participant had difficulty identifying physical attributes he was encouraged to repeat the movement several times. If the participant was able to identify specific physical attributes that identified his movement pattern, the instructor would move on to Step 2, and work with the participant to problem-solve a strategy to modify the movement.

If the participant was not able to identify his preferred movement pattern, external feedback was provided using additional visual or tactile cues. The first external feedback option available was a mirror. For this option, a full-length mirror was placed in a position that provided the participant a lateral view of his body. This allowed the participant to visually observe his lumbar movement when picking up the object. While observing his movement in the mirror, the participant then performed several trials of the activity using his preferred movement strategy. The participant was instructed to pay attention to the movement of the lumbar spine in the mirror, and any physical attributes that were associated with the movement. If the participant was able to identify specific physical attributes associated with his movement pattern, the instructor would move on to Step 2 and work with the participant to problem-solve a strategy to modify the movement.

If the participant continued to have difficulty identifying his preferred movement pattern using the mirror, the participant then used tactile cues. Specifically, the participant was instructed to place a hand or both hands at a comfortable location on his lumbar spine. The participant then performed several repetitions of the activity using his preferred movement strategy with his tactile cues. The participant was instructed to pay attention to the movement of the lumbar spine, and any physical attributes that were associated with the movement. If the participant was able to identify specific physical attributes that identified his movement pattern, the instructor would move on to Step 2 and work with the participant to problem-solve a strategy to modify the movement.

If the participant continued to have difficulty identifying his preferred movement strategy with his tactile cues, then the instructor provided tactile cues. Specifically, the instructor placed a hand or both hands on the participant’s lumbar spine. The participant then performed several repetitions of the activity using his preferred movement strategy with tactile cues provided by the instructor. Once the participant was able to identify his preferred movement strategy, the instructor would move on to Step 2 and work with the participant to problem-solve a strategy to modify the movement.

**Step 2) Problem-solve a modification**
Once the participant was able to correctly identify the lumbar movement pattern during his preferred movement, the participant was asked to problem-solve a method to perform the same movement with less lumbar motion in the early part of the movement. The participant was prompted to think about what other parts of the body could be used to perform more of the movement if the goal was to minimize the movement of the lumbar spine. An example of prompting by the instructor to the participant was as follows:

Instructor: You have said that you feel an increase in symptoms in your low back when you perform this activity. What could you do to perform the same activity but not feel an increase in your symptoms?
Participant: Try to keep my back from moving too soon?
Instructor: So if you still need to complete the activity, and you are going to try to keep your low back from moving too soon, what other areas of the body might you be able to move more?
Participant: Maybe move more at the hips?
Instructor: I agree. Why don’t you try performing the activity, and think about moving more at the hips when you start the movement.

The participant was provided an opportunity to practice various movement strategies with verbal feedback and cueing from the tester. If the participant needed additional cueing, the tester suggested that the participant try to move more at the hips when initiating the movement.

**Step 3) Identify the modified strategy**

Once the participant was able to problem-solve a modified movement strategy, the participant was asked to perform several repetitions of the activity using the modified movement strategy. After several repetitions of the activity, the participant was asked to identify physical attributes that would let him know he performed the movement differently (i.e., hamstrings stretching, less symptoms). An example of prompting by the instructor to the participant was as follows:

Instructor: Do you think you were moving less in your low back when you initiated the movement?
Participant: I think so, yes.
Instructor: I agree. I think your movement looks a lot better. Go ahead and practice a few more times. Pay attention to what you feel that lets you know you are moving less in your low back when you initiate the movement.
(Participant practices several times)
Participant: I don’t feel my usual back pain, and I feel some tension through my hamstrings that I don’t usually feel.
If the participant required any extrinsic feedback in the form of visual or tactile cues (e.g., mirror) in Step 1, then the extrinsic cues were removed. The participant then performed several repetitions of the activity without the use of visual or tactile cues. After several repetitions of the activity, the participant was asked to identify physical attributes that would let him know he performed the movement differently. Once the participant was able to identify physical attributes of his modified movement strategy, the instructor would move on to Step 4 and work with the participant to practice the modified strategy.

**Step 4) Practice the modified strategy**

Once the participant was able to identify a modified movement strategy, he was asked to practice the PUO activity using the newly identified strategy. Once the participant was able to consistently perform the modified movement strategy, any remaining time was spent having the participant practice performing varying conditions of the PUO activity. For example, the instructor may have initially varied the location of the object, then he might have adjusted the weight of the object. Additionally, the instructor may have simulated a similar task that the participant stated was problematic in his everyday life. If time permitted, the participant practiced the activity while varying his attention to the task. For example, the instructor would engage the participant in a conversation while performing the activity. At the completion of the session, the instructor asked the participant to verbalize what was covered in the session. Specifically, the instructor prompted the participant to verbalize what he learned about his preferred movement pattern, and how he was able to modify his movement pattern.
Chapter 5: Summary and Significance
5.1 Summary and Significance

The primary goals of this dissertation project were to examine the (1) lumbar movement pattern during a standardized clinical test and a functional activity test, (2) differences in the lumbar movement pattern between people with LBP and back-healthy people, (3) association between the lumbar movement pattern and functional limitation, (4) consistency of the lumbar movement pattern when a functional activity was varied. We also examined the (1) ability of people with LBP to modify their lumbar movement pattern during a functional activity, (2) effect of modifying the lumbar movement pattern on LBP symptoms, and (3) characteristics of people with LBP that influence the ability to modify the movement pattern.

The purpose of chapter 2 was to examine the lumbar movement pattern during a standardized clinical test and a functional activity test in both people with LBP and back-healthy people. The study was conducted because it was not known whether the lumbar movement pattern observed during a standardized clinical test reflected the movement pattern used during a common functional activity. We found that the lumbar movement pattern was similar between the two tests for both people with LBP and back-healthy people. Thus, how a person moved during the clinical test of FWB was highly associated with how they moved during the functional activity test of PUO. This is important because standardized clinical tests such as FWB are used in a clinical examination to assess lumbar motion, as well as for making clinical judgements of the presence of altered movement patterns.\(^1\) However, in chapter 2 we also found that compared to back-healthy people and people with LBP and low levels of functional limitation, people with LBP and high levels of functional limitation displayed an altered movement pattern of greater early-phase lumbar excursion during only the functional activity test. So, while the lumbar
movement pattern was highly associated between the two movement tests, the altered movement pattern was only observable during the functional activity test. Given that the primary reason people with LBP seek care is limitation in function, it may be more efficient and effective to use the standardized PUO test to assess altered lumbar movement patterns during a clinical examination rather than the traditional FWB test. Additionally, findings from the PUO test may be seamlessly incorporated into treatment of LBP designed to modify altered lumbar movement patterns during functional activities.

In chapter 2 we also examined the association between functional limitation and the lumbar movement pattern for both the FWB and the PUO tests. We found that for all participants with LBP, the amount of early-phase lumbar excursion during each test was associated with a person’s self-report of functional limitation. Thus, the more early-phase lumbar excursion a person displayed for each test, the greater the person’s functional limitation. While not statistically different, the amount of early-phase lumbar excursion during the functional activity test of PUO explained 36% of the variance in functional limitation, i.e., twice the variance, of that explained by early-lumbar excursion during the clinical test of FWB (16% of the variance). Therefore, our results suggest that how a person moves his lumbar spine during a functional activity is more related to his limitation in function than how a person moves during a clinical test. The overall findings from chapter 2 suggest that the lumbar movement pattern observed during a standardized clinical test is similar to the lumbar movement pattern used during a standardized functional activity test. Assessing the lumbar movement pattern during a functional activity test, however, may provide more insight into altered movement patterns and how the movement pattern may contribute to a person’s functional limitation than that obtained with a
The purpose of chapter 3 was to examine the (1) consistency of an aspect of the lumbar movement pattern used during a functional activity when the conditions of the activity were varied, and (2) association between the lumbar movement pattern and a person’s self-report of functional limitation. The rationale for the study was based on the proposal that people with LBP adopt an altered movement pattern that is repeated during performance of functional activities across the day. The repetition of an altered movement pattern across activities is considered important because it may accelerate the accumulation of localized areas of tissue stress. The results presented in chapter 2 indicate that people with LBP and high levels of functional limitation display an altered movement pattern of greater early-phase lumbar excursion during a functional activity test compared to back-healthy people and people with LBP and low levels of functional limitation. Therefore, varying the conditions of a functional activity test is a logical first approach to examine the consistency of the lumbar movement pattern identified in people with LBP and high levels of functional limitation. In the study we found that, compared to back-healthy people and people with LBP and low levels of functional limitation, people with LBP and high levels of functional limitation consistently displayed greater early-phase lumbar excursion in each of the functional activity conditions. We also found that in people with LBP the amount of early-phase lumbar excursion was consistently associated with a person’s self-report of functional limitation. Our results lend initial support to the proposal that people with LBP may use an altered lumbar movement pattern consistently across functional activities, and the repetition of the movement pattern may contribute to the person’s functional limitations. We propose that the consistent use of the same lumbar movement pattern across the day could lead to
concentrations of stress in specific tissues in the lumbar region, eventually resulting in LBP symptoms and potentially micro- or macro-trauma. Additionally, a person with LBP may experience recurrent or persistent symptoms and functional limitation(s) unless the movement pattern is modified.

The purpose of chapter 4 was to examine the ability of people with LBP to modify an aspect of their lumbar movement pattern during a functional activity test within a single session of motor skills training. We also were interested in examining the effect of modifying the lumbar movement pattern on LBP symptoms. Additionally, we examined the characteristics of people with LBP that influenced their ability to modify their preferred lumbar movement pattern during performance of the functional activity test. The rationale for the study was based on previous research that reported people with LBP were able to modify an aspect of their lumbar movement pattern during a clinical test.\(^6\) Additionally, previous research has identified that modifying an altered lumbar movement pattern results in an immediate improvement in LBP symptoms.\(^7,8\) The current study was conducted, therefore, because it was not known whether people with LBP could modify their altered lumbar movement pattern during a functional activity test, and whether modifying the lumbar movement pattern would result in an improvement in LBP symptoms. We found that, prior to training people with LBP demonstrated an altered movement pattern of greater early-phase lumbar excursion compared to back-healthy people. We found that people with LBP were able to significantly reduce the amount of early-phase lumbar excursion during the performance of a functional activity following a single, 20-minute session of motor skills training. We also found that modifying the movement pattern resulted in a significant decrease in the number of people who reported increased LBP symptoms during the functional
activity test. The characteristics that predicted the ability to modify the lumbar movement pattern were the amount of early-phase lumbar excursion displayed during the test when a person used his preferred movement strategy, and the duration of LBP history. Thus, people with LBP who displayed greater amounts of early-phase lumbar excursion, and those who had LBP symptoms for a longer duration, were the people who demonstrated the greatest ability to modify their movement pattern. Our results suggest that for people with LBP who display an altered movement pattern of greater early-phase lumbar excursion, motor skills training may be an effective approach to modify the lumbar movement pattern and reduce LBP symptoms during the performance of a functional activity.

5.2 Future studies

In chapter 2, we found that the lumbar movement pattern displayed during a clinical test was similar to the pattern displayed during a functional activity test for both people with LBP and back-healthy people. We also found that people with LBP and high levels of functional limitation displayed an altered movement pattern of greater early-phase lumbar excursion compared to people with LBP and low levels of functional limitation and back-healthy people. A limitation of the study was that we examined only one clinical test and one functional activity that both were performed in the sagittal plane. In future studies it would be important to examine the association between the lumbar movement pattern observed during other standardized clinical tests and functional activities, as well as examine the movement pattern when the tests involve movement of the spine in more than one plane. Additional studies also may examine subgroups of people with LBP, as prior research has demonstrated differences in the lumbar movement pattern between subgroups during clinical tests.\textsuperscript{9,10} Therefore, it would be important
to examine whether subgroups of people with LBP display similar differences in the lumbar movement pattern during functional activities. Because we propose that people with LBP adopt an altered movement pattern that is repeated during performance of functional activities across the day, we hypothesize that differences in movement patterns observed between subgroups during clinical tests also would be observed during functional activities. Information obtained from the future studies would provide additional evidence for the proposal that people with LBP display specific altered lumbar movement patterns that are repeated throughout the performance of daily functional activities.

In chapter 3 we found that people with LBP and high levels of functional limitation consistently displayed an altered lumbar movement pattern when aspects of a functional activity were varied. Specifically, people with LBP and high levels of functional limitations consistently displayed a pattern of greater early-phase lumbar excursion across the test conditions compared to people with LBP and low levels of functional limitation and back-healthy people. One limitation of the current study is that aspects of the functional activity were all varied in the sagittal plane. Therefore, future studies should examine the consistency of the lumbar movement pattern used during multi-planar functional activities. We hypothesize that people with high levels of functional limitation would consistently display an altered lumbar movement pattern during multi-planar functional activity tests. An additional limitation of the current study is that the performance of the functional activity test in the laboratory setting may not reflect the actual circumstances encountered during the performance of everyday functional activities. Therefore, as wearable sensor technology improves and allows for objective kinematic measurements outside of the laboratory, future studies should examine aspects of the lumbar movement
pattern across a typical day.

In chapter 4 we examined the effects of a single session of motor skills training on the preferred lumbar movement pattern and LBP symptoms during performance of a functional activity, as well as the characteristics of people with LBP that influenced the ability to modify the preferred lumbar movement pattern. Specifically, we were interested in whether people with LBP could reduce the amount of early-phase lumbar excursion during a functional activity. We found that, compared to back-healthy people, people with LBP displayed an altered movement pattern of greater early-phase lumbar excursion using their preferred strategy during the functional activity test. Following training, we found that people with LBP significantly reduced the amount of early-phase lumbar excursion during a functional activity, and displayed a lumbar movement pattern similar to the back-healthy people. We also found that a significant number of participants with LBP reported decreased LBP symptoms during the functional activity following the motor skills training. Additionally, our results indicate that the people who displayed the greatest amount of early-phase lumbar excursion when they used their preferred movement strategy during the test, and the people with the longest history of LBP were the people who demonstrated the greatest change in their lumbar movement pattern following training. These results are counter-intuitive yet encouraging because they suggest that the people who are most impaired, i.e., present with the most altered movement pattern and the longest duration of LBP, can still modify their movement pattern after training. One limitation of the study is that the motor skills training session and laboratory testing were conducted on the same day. Thus, it is unknown whether the modified movement pattern would be retained beyond the initial laboratory session. Additionally, our results indicate that modifying the lumbar movement
pattern had an immediate effect on LBP symptoms during the performance of the functional activity. It is unknown whether modifying the lumbar movement pattern will affect LBP symptoms on the following day. Future studies, therefore, should examine both the retention of the motor skill practiced during the training and the effect on LBP symptoms by repeating the kinematic testing at a later date. Since modifying the lumbar movement pattern had an immediate effect on LBP symptoms in our study, we hypothesize that the people who retain the modified movement pattern also will report decreased LBP symptoms when testing is repeated at a later date. An additional limitation of the current study is that only one functional activity was examined. Future studies should examine the ability of people with LBP to transfer a modified lumbar movement pattern to additional functional activities following training of a single activity. Prior research has shown that training on one task can result in a transfer of training to additional tasks. Since our research indicates that people with LBP consistently display an altered lumbar movement pattern across a range of functional activity tests, we hypothesize that people with LBP would transfer the learning of a modified movement pattern to other functional activities. Modifying the lumbar movement pattern is important because the altered lumbar movement pattern is associated with a person’s self-report of functional limitation. Identifying and modifying the movement-related processes proposed to contribute to the development and course of LBP may be an important component of management that would reduce the recurrent or persistent symptoms and functional limitations that often characterize a person’s LBP condition.
5.3 References


